FINAL REPORT

on

A STUDY OF ALLOYS SUITABLE FOR USE AS UNITED STATES COINAGE

to

U.S. DEPARTMENT OF THE TREASURY
BUREAU OF THE MINT

February 12, 1965

by

BATTELLE MEMORIAL INSTITUTE
505 King Avenue
Columbus, Ohio 43201

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February 12, 1965

Miss Eva Adams
Director of the Mint
U. S. Treasury Department
Washington 25, D. C.

Dear Miss Adams:

We are pleased to submit herewith 200 copies of our Final Report on "A Study of Alloys Suitable for Use as United States Coinage".

As the report indicates, no single material was found which could entirely satisfy all the criteria, both the subjective and objective ones. We believe, however, that the recommended alternatives represent satisfactory compromises that consider the many criteria and points of view brought to light by our investigation.

The other Battelle staff members join me in expressing thanks for the opportunity we have been given to work on this project. We have enjoyed working with you and your staff, as well as other members of the Treasury Department staff.

Please call upon us if we can be of additional assistance at any time.

Very truly yours,

H J Wagner

H. J. Wagner
Associate Chief
Ferrous and High-Alloy
Metallurgy Division

HJW:lh
Enc. (200)

ACKNOWLEDGMENT

The authors wish to thank the Bureau of the Mint and the Treasury Department for the excellent cooperation received during this research and in the preparation of this report. In addition, the contributions of various Battelle staff members in the Department of Materials Engineering, Department of Economics and Information Research, and Department of Process and Physical Metallurgy are appreciated.

The contributions and cooperation received from the various metal producers, fabricators, silver consumers, silver producers, coin-selector manufacturers, and the operators of coin-activated machines are gratefully acknowledged.

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A STUDY OF ALLOYS SUITABLE FOR USE AS UNITED STATES COINAGE

by

L. P. Rice, M. E. Emerson, H. J. Wagner,
R. W. Hale, and A. M. Hall

SUMMARY

This report contains the results of a study of materials that could be considered as alternatives to the present 90 silver-10 copper alloy used in United States coinage. Evaluation of candidate materials was made on the basis of the following criteria:

- Availability and Price
- Public acceptability
- Physical, chemical, and mechanical properties
- Effect on coin-operated devices
- Effect on mint operations
- Counterfeiting, illegal duplication, and slugging potential.

Included in these criteria were considerations of the supply and demand picture from the present time to the year 2000 for silver and various base metals.

No material can entirely satisfy all the criteria, though certain materials are outstanding in one respect or another. For example, the present silver-copper alloy is excellent in every respect except that it does not satisfy the availability and price criterion. The study indicates that the Treasury silver stocks will be depleted in 3 to 8 years (depending on the demand for coinage) if the current alloy is continued. It is judged that a limit of about 15 per cent should be placed on the silver content of the coinage material, so that the Treasury stocks can be maintained for a long enough period of time to serve as a means of preventing a rise in the price of silver.

Cupronickel (75 copper-25 nickel) is attractive from the standpoint of the transition to the new coinage, because of the ease with which it could be adapted to Mint operations. However, it would not be completely acceptable in coin-operated devices.

One acceptable solution, though not satisfying every criterion to the fullest extent desired, would be the use of a composite material. One such material is a sandwich-like combination that combines into outside layers, elements of appearance and, in its core, physical properties that make the composite completely compatible with present coinage alloys in coin-operated devices.

It is recommended that a composite material be adopted consisting of a 75 copper-25 nickel alloy on the outside and a core of copper. It is also recommended that the Mint take whatever steps are required to establish the availability of the material and the feasibility of maintaining quality control under mass-production conditions.

If the multilayer composite should be disqualified for unforeseen reasons, it is recommended that the new coins be made from the homogeneous 75 copper-25 nickel alloy.

If the retention of silver because of tradition and prestige does not compromise any of the other objectives, it is recommended that either of two options be chosen. One is to use silver in the 50-cent piece only, by making a multilayer composite consisting of 80 silver-20 copper on the outside, and a low silver-copper alloy in the core. The other option is to spread the silver evenly throughout all subsidiary denominations by making a composite consisting of the 40 silver-50 copper-5 nickel-5 zinc alloy on a silver-bearing copper alloy core. It is further recommended that the silver-containing coins, if adopted, be changed to the 75 copper-25 nickel on a copper core on July 1, 1975, or at such time as the Treasury stock of silver reaches a predetermined minimum.

A STUDY OF ALLOYS SUITABLE FOR USE AS UNITED STATES COINAGE

L. P. Rice, M. E. Emerson, H. J. Wagner,
R. W. Hale, and A. M. Hall

INTRODUCTION

During the past few years, the Treasury of the United States has watched with growing concern the increasing rate of consumption of its silver stocks, its principal source of silver for coinage. The concern arises from the fact that the amount of silver used for minting subsidiary coinage (dimes, quarters, and half dollars) has been increasing so rapidly that there is danger that the supply of silver from the Treasury stocks and mine production will soon not be adequate to fulfill the combined needs for coinage, industry, and defense.

Because of the imbalance in supply and demand, the possibility has been considered of changing the present silver coinage alloy, set by Congress at 90 per cent silver - 10 per cent copper. As one facet of its investigation of the situation, the Treasury Department, Bureau of the Mint, engaged Battelle Memorial Institute to make a study of coinage materials.

The purpose of this study was to examine the silver supply and demand picture, identify and evaluate various possible substitutes for the present alloy, and to recommend the most suitable alternative on the basis of available facts, reasonable estimates, and engineering judgment. This study did not delve deeply into the political or economic consequences of a change from our present silver coinage to some other alloy, except where such effects are closely related to the choice of a particular metal or alloy.

There is general agreement among members of the Treasury Department, silver producers, silver consumers, and economists that the available Treasury stocks of silver for coinage will be depleted in the not-too-distant future. The area of disagreement is in the length of time for depletion to be complete, and in the best solution to the problem.

A great number of solutions have been offered since the problem was first brought to light. Most of these suggestions are based on metallic coinage and include suggestions both for lowering the silver content of the present alloy and for eliminating silver entirely. However, suggestions have also been offered for nonmetallic coinage materials, such as plastics and ceramics.

In an effort to obtain a balanced perspective of possible approaches to this problem, a broad spectrum of metals, alloys, and nonmetallic materials that might be used for coinage is considered and evaluated in this report.

The substitution of a new silver-free alloy, or even a small change in the silver content of our coinage alloy, presents many problems which are at once complex and controversial. This will be understood by noting the following criteria that have been taken into account in judging the suitability of various candidate metals, alloys, or nonmetallic materials:

- Availability and price
- Public acceptability
- Physical, chemical, and mechanical properties
- Effect on coin-operated devices
- Effect on Mint operations
- Counterfeiting, illegal duplication, and slugging potential.

These criteria are discussed in detail in the next section of this report.

CRITERIA FOR SELECTING ALTERNATIVE COINAGE MATERIALS

A number of criteria for rating candidate materials are listed below and discussed in some detail. It is believed that all of the important factors governing the choice of a coinage alloy are included.

Availability and Price

The primary reason for the present predicament in silver coinage is the increasing price and decreasing Treasury supply of silver. It is most important, therefore, that the recommended alternative be available at reasonable price and in sufficient quantities for many years to come.

Price and availability depend on a number of factors, such as geographic location of the sources of supply, present usage and estimated future trends in usage, number of suppliers, and Government stockpiles for defense purposes. From the standpoint of international politics and economics, it would be best for the sources of supply to be in the United States. Barring this possibility, however, it would be preferable that the supply of raw material be available in the needed quantities on the North American continent. Under all but the most extraordinary circumstances, this would insure the Treasury of an adequate supply should imports be interrupted or cut off.

A description of the present and future supply-and-demand picture for selected candidate materials is found in Appendix A.

Public Acceptability

Judging from the widespread attention paid to the current problem in the public press, and the feelings expressed by members of Congress and other Government officials, the reaction of the public to a change in coinage materials is a most important factor. Acceptability to the public, however, is a subjective criterion which is not measurable by any simple scientific test or series of tests. If sufficient time were available, a public poll using carefully chosen sampling techniques might provide some measure of public acceptability for a new coinage material. In the present report, the evaluation of various materials from this viewpoint is based on judgments of the reasons for public acceptance or rejection of certain materials.

Public acceptability, it is believed, is related to a number of more easily recognized factors. For example, experience with genuine coins has enabled the public to distinguish genuine coins from counterfeit ones on the basis of such factors as color, weight, brittleness, bounce, and ring. It would seem prudent, from this viewpoint, to select substitute materials that are in some way unique, so that the public can easily distinguish between genuine and counterfeit coins. It is quite likely that a coin which cannot be "trusted" would not be acceptable. An unknown factor, in assessing acceptability, is whether the public would prefer a coin that was close to the present coinage

in color, weight, bounce, ring, etc.; or whether, given the need for a replacement, the public would prefer another type of easily distinguishable material.

Counterfeit potential and criteria for mechanical, chemical, and physical properties are discussed in further detail below. Before discussing them, however, another factor, also related to both counterfeit potential and public acceptability, should be given consideration, that of intrinsic value.

Intrinsic Value. Intrinsic value, as used here, means the value placed on such materials as gold, silver, or diamonds by virtue of their traditional position in a given civilization as materials of worth or esteem. Such materials often serve as media of exchange. The market value may or may not be influenced by the utility of these materials in an industrialized nation. In earlier times, coins containing silver were used because of their intrinsic value. On the other hand, fiduciary coinage (coinage whose metal value is less than its face value) has also been in common use. In fact, until recently, U. S. silver coinage has been essentially fiduciary in nature. At the present time, however, the price of silver has risen to the point where the United States silver dollar actually contains one dollar's worth of silver. Furthermore, in the other silver coins (dimes, quarters, and half dollars), the silver market value has approached the face value. This trend is actually unfortunate. In effect, the high market value of our present silver coinage has become a liability. The reason is that it is now necessary for the Government to prevent the price of silver from rising above the point at which the metal value exceeds the face value of the coinage, at which point coins might be melted down for their silver content. This the Government does by supplying silver from its reserves at $1.2929 per ounce, which is the "melt point" of the silver dollar. This silver-sales activity constitutes another serious drain on Government silver stocks in addition to the unprecedented demand from coinage.

There is potential danger in any coinage material that might rise in market value as silver has done. Technological progress results in ever-increasing demands for nearly all materials, especially for metals and alloys. Thus, some technical advance could make a significant difference in the supply and demand of any high-price material used in coinage for its intrinsic value. The situation now existing with silver could then occur with other metals.

Public feeling with respect to intrinsic value in our coinage is perhaps associated with tradition rather than a realization of actual metallic value. Arguments have been advanced both for and against coinage having significant intrinsic value. Evaluation of these arguments is a difficult matter and is regarded as lying beyond the scope of the present study. However, this factor does have relevance as far as counterfeiting is concerned, which is discussed in a following section.

Physical, Chemical, and Mechanical Properties

Physical, chemical, and mechanical properties provide the most objective basis upon which to select a coinage material. By contrast, the public-acceptability factor will probably be a subjective matter, since it depends on the public's attitudes rather

than its technical knowledge. The physical, chemical, and mechanical properties which are desirable in coinage are discussed in the paragraphs that follow.

Color. For well over 150 years, the most valuable denominations of U.S. coins (other than gold) have been characterized by the bright white color of the 90 silver-10 copper alloy. Therefore, it is reasonable to surmise that the public will be more likely to accept a new coinage material for dimes, quarters, and half dollars if the color is similar to that of the silver alloy currently used for these denominations. If these coins were made from copper or red brass, they would probably have low acceptability, because they would look like the U.S. one-cent coin, or the low-denomination coins of various foreign countries. A yellow coin (brass colored) might be more acceptable than a red one because there are no U.S. traditions other than gold coins associated with that color.

Density. The public probably is less likely to accept a new coinage material that differs markedly in density from the present silver alloy to which it has become accustomed. For example (assuming no change in coin dimensions), an aluminum coin, though white in color, would be immediately noted because of its low density (2.7 grams per cubic centimeter for aluminum, compared with 10.3 grams per cubic centimeter for the present silver-base alloy). The same reasoning would apply in the case of a material much heavier than the present alloy, such as lead or tungsten. The public probably associates "off weight" with counterfeit coins or play money. In spite of these considerations, a number of countries now have aluminum coins. However, it must be recognized that the problems associated with the introduction of aluminum coins are considerably different in these countries than they would be in the United States.

Density also plays a part in coin-operated devices, which require a certain minimum weight to actuate the mechanisms. A coin that is too light is undesirable.

Mechanical Properties. Certain mechanical properties are highly desirable. For example, a metal should be soft and ductile enough so that it may be readily rolled, blanked, and coined. At the same time, it should possess enough wear resistance after coining to have a useful life in normal circulation of about 25 to 30 years. The harder the metal the better the wear resistance. On the other hand, as the hardness increases, the "coinability" decreases, and fewer coins can be made with a given set of dies. Hence, some compromise is called for.

Chemical Properties. One chemical property important in coins is good corrosion resistance. Coins in circulation are exposed to such things as perspiration, coffee, soft drinks, and moisture. Good corrosion resistance is also required to preserve the original luster and color of the newly minted coin. As an example, zinc, which has been used for coinage by 2 or 3 countries, darkens by corrosion and has an unpleasant appearance after having been in circulation a while. In addition, the material should be essentially nonreactive and nontoxic if accidentally swallowed.

Ring. The "ring" emitted by a coin when it is struck, or dropped on a hard surface, is a familiar sound. This criterion is clearly one related to public acceptability.

The unique ring of the present silver coins cannot be overlooked as an anti-counterfeiting factor. Moreover, some emphasis has been placed upon it in recent publicity releases. Technically, metallic ring is probably associated with the modulus of elasticity, residual stresses, and damping capacity of the material in question. It probably can be adjusted in any given alloy by varying the coin geometry, heat treatment, or cold working. Regardless of its physical nature, a metallic "ring" is associated by many people with genuineness.

Physical Properties. Among the physical properties of coins, the electrical and magnetic properties have a profound effect upon their everyday usage as media of exchange under certain circumstances. These effects are discussed below in relation to the use of coins in coin-operated devices.

Effect on Coin-Operated Devices

The ability of coins to be accepted in coin-operated devices is considered as a separate criterion, even though basic physical properties, such as density, magnetic attraction, and electrical conductivity are involved. Vending of goods and services in coin-operated equipment has become a large industry in the United States. Nearly everyone makes use of such coin-operated devices as pay telephones, cigarette and candy machines, toll-road collection boxes, juke boxes, and many others.

Considered as individual industries, the two largest users of coins are the vending-machine industry (merchandise only) and pay telephones. It has been estimated that in 1963, about 28 billion coins passed through vending machines*, while another 4 to 5 billion coins went into the pay telephones of the Bell System alone.**

All industries which use coin-operated devices have a large investment in coin-handling equipment, and they are therefore very much concerned about any changes in the coinage alloy. The successful operation of this type of business depends to a large degree on special devices, which are referred to in this report as "coin selectors" (see Appendix C). Although these devices vary in degree of sophistication, their main purpose is to accept genuine United States coins and reject all foreign coins*** and slugs. An essential feature of their ability to discriminate between good and unacceptable coins depends on the so-called "eddy-current" principle. The application of this principle is based on the fact that United States coinage is nonmagnetic and has certain definite values of electrical resistivity. If the material selected to supplant the present silver coins were magnetic, such as iron, or had a high resistivity, the new dimes, quarters, and half dollars would be rejected by the present coin-selector mechanisms. Introduction of a new material that differs markedly from the old might require a major alteration in each of the several millions of these devices now in operation. Some consideration must therefore be given to these industries. If possible, any new coin material that may be recommended should be usable in the present coin-operated devices, with the minimum amount of disruption in business or alteration of equipment.

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* Data courtesy National Automatic Merchandising Association. Breakdown was as follows: 1-cent coin — 2.3 billion pieces; 5-cent coin — 10.4 billion pieces, 10-cent coin — 10.9 billion pieces; 25-cent coin — 4.8 billion pieces.

** Data courtesy Bell Telephone Laboratories.

*** Adjustments to accept Canadian quarters can be made in the machines.

Effect on Mint Operations

Two Mints are now in operation, one in Philadelphia and one in Denver. They are long-established facilities, and are geared specifically to handle the melting, rolling, blanking, and coining of copper- and silver-base alloys. Thus, in effect, each Mint is an integrated unit with essentially "in house" control of all steps in the process of making coins from melting to the final inspection, counting, and sacking operations. The nature of the operating facilities at each mint, particularly at the Philadelphia Mint, imposes certain limitations on the kind of coinage alloy that can be handled. Much of the equipment is old and of insufficient capacity. However, this is not a serious obstacle at present because only three simple alloys are processed, as shown in the following tabulation:

Coin	Alloy Composition, per cent			
	Copper	Silver	Zinc	Nickel
One cent	95	--	5	--
Five cent	75	--	--	25
Dime	10	90	--	--
Quarter	10	90	--	--
Half dollar	10	90	--	--

Each of the three alloys is relatively easy to melt and cast into rectangular ingots in the Mints' melt shops. The alloys are also easy to roll, and require no hot rolling. Hence, no hot-rolling equipment is available. Facilities for intermediate annealing between cold-rolling operations are available, however. Because the cast metal slabs are relatively small, no heavy breakdown rolls are used.

An additional limiting factor at the mint level is the present coinage presses. These presses, some of which are more than 60 years old, have a design load limit of 150 tons (coinage force). Some of them are actually operated at loads somewhat above their design limit.

Congress has authorized the contruction of a new Mint in Philadelphia. It will be equipped with modern high-capacity equipment. However, the new Mint will probably not be ready for operation for several years. If Congress authorizes a substitute coinage material during 1965, the new coins would necessarily have to be made in the present Mints. The Mints could, of course, buy strip from outside vendors if the new alloy were difficult to melt and roll, but the material would still have to go through the present coin presses. It is apparent, therefore, that the limitations of both of the present Mints must be carefully considered before choosing a substitute for the present silver coinage alloy.

Counterfeiting, Illegal Duplication, and Slugging Potential

The possibilities for illegal manufacture of coins or slugs constitute a group of related criteria requiring considederation. Neither counterfeiting nor illegal duplication of United States coinage is a serious problem at the present time. Counterfeiting

is defined as the clandestine manufacture of replicas or reproductions of United States design, but in lower cost metals. That counterfeiting and illegal duplication have not been problems is the result of two factors:

(1) The copper cent and the cupronickel five-cent piece offer little profit potential for the effort expended in counterfeiting or duplicating them.

(2) Duplicating of the silver coins (dimes, quarters, and half dollars) is made unprofitable because of the high intrinsic value of their silver content. The color, density, "ring", and electrical properties cannot be reproduced with metals other than silver-base alloys. Therefore, counterfeit coins made of base metals are easily detected.

If a base metal or base-metal alloy is selected as a substitute for the present silver coinage, the incentive for illegal duplication will increase because the face value of the coins will be much greater than the market value of the material they are made of.

A second factor, related to counterfeiting, is "slugging"; that is, deliberate manufacture of disks, or importing of low-value foreign coins, to be substituted for genuine coinage in various coin-operated mechanisms. If coin-operated devices are adjusted to accept an entirely new type of coinage material, the ease of obtaining such a material for use as slugs must be considered in choosing the substitute material.

OUTLOOK FOR THE AVAILABILITY OF SILVER AS A COINAGE MATERIAL

Since World War II, world consumption of silver has exceeded production, the deficit having been drawn from stocks. Most recently, the depletion of this stock has been accelerated through rising industrial needs accompanied by burgeoning coinage requirements in the United States. This situation, coupled with inelastic production potential and limited resources, has precipitated an imbalance in supply which demands corrective action.

About two-thirds of the silver consumed in the Free World has been for industrial uses (arts and industry). The rest is utilized in coinage.

In the 1963 calendar year, as shown below, 419 million ounces of silver were used in the Free World for industrial uses and in coinage, resulting in a deficit of 209 million ounces. This deficit was equivalent to the total Free World silver production for that year. The data show that supply and demand for the metal are more nearly in balance in other Free World countries and that the problem of scarcity of silver is centered in the United States.

	Millions of Troy Ounces[a]		
1963	United States	Other Free World	Total Free World
Production	35	175	210
Consumption			
Arts and industry	110	137	247
Coinage	111	61	172
Total	221	198	419
Deficit (production minus consumption)	(186)	(23)	(209)

(a) Note that all "ounces" referred to in this report are troy ounces.

Data show that the Free World deficit in silver in 1964 was 341 million ounces, up from 209 million ounces in 1963.* Most of this increase was due to increased use of silver in U. S. coinage, which was 203 million ounces in 1964, up from 111 million ounces the previous year. Silver used in U. S. coinage in 1964 therefore was almost equal to the 215 million ounces of silver produced in the Free World for that year.

In 1964, as in previous years, most of this Free World deficit was made up by withdrawals from the U. S. Treasury stock of monetary silver.** This is illustrated for 1964 as follows:

* "The Silver Market in 1964", Handy and Harman, New York.

** In addition, 19.8 million ounces of silver in silver dollars was withdrawn from the Treasury in 1964. Most of this silver went into hoarding and was not used to finance the world deficit.

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		Millions of Troy Ounces
Total Free World deficit (1964)		341
Withdrawals from U. S. Treasury		
Subsidiary Coinage	203	
Redemptions of Silver Certificates	141	
Net Change	344	344
Total Stock of Silver, U. S. Treasury, December 31, 1963		1,584
Total Stock of Silver, U. S. Treasury, December 31, 1964		1,220
Net Change		(364)

The net withdrawal from the Treasury for 1964, therefore, was 364 million ounces.

The order to propose a solution to the shortage of silver it is important to establish the adequacy of the U.S. monetary stock of silver for projected coinage needs. This forecast then serves as a basis for evaluating alternatives for alleviating the projected scarcity of the metal.

In Appendix B a projection is made of the life expectancy of the Treasury stock of silver based upon total Free World supply and demand for silver in future years. This forecast combines conditions of high Free World productivity (higher than the average over the past 15 years) of silver with only moderate increases in demand (2 per cent per year compared to 4 per cent per year since 1950) by industry and the arts in the Free World, together with decreasing coinage in other Free World countries.* The uncertainty of the forecast of future demands for U.S. coinage is reduced through the consideration of three situations involving high, medium, and low rates of coinage demand. Table 1 is a summary of the results of this forecast.

The table shows that should the present demand for coinage persist, the U.S. monetary stock of silver could be exhausted in little more than 3 years, assuming no change in the present 90 silver-10 copper alloy. If the silver content of U. S. coins were reduced to 50 per cent, the forecast shows that this stock would be exhausted by 1975, even under the lowest level of expected coinage demand. However, the life of the Treasury stock could possibly be extended to 1979 by reducing the silver content of coins to 15 per cent.** Eliminating silver from U.S. coinage altogether might extend this stock through 1983.

* It is assumed that most of the projected world deficit in silver, excluding U. S. coinage, will be covered by withdrawals from Treasury stocks through the redemption of silver certificates. No provision is made for the minting of silver dollars.

** If an alloy containing 15 per cent silver is technically undesirable, one possiblity would be to accomplish the reduced silver consumption rate by adopting a 50 silver-50 copper alloy for a single denomination.

TABLE 1. SUMMARY SHOWING YEAR IN WHICH U.S. MONETARY STOCK OF SILVER WOULD BE EXHAUSTED, DEPENDING ON THE SILVER CONTENT OF THE COINAGE AND THE DEMAND FOR COINS

	Alternative Silver Content of U. S. Coins, per cent[a]				
Level of Coinage Demand	90	50	30	15	0
I. High Level – Coinage production at full Mint capacity of about 300 million ounces per year	1968	1969	1971	1974[b]	1979[b]
II. Medium Level – Continuation of 1964 coinage rate of about 200 million ounces per year	1969	1971	1973	1976	1980
III. Low Level – Cyclic down-turn in coinage demand beginning early in 1965	1973	1975	1977	1979	1983

(a) In these projections it is assumed that changes in silver content of U. S. coins would not become effective until December 31, 1965.

(b) It should be noted that industrial demand for 1964 was at a very high level. If it should increase at the rate of 2 per cent per year from this level, the Treasury stocks could be exhausted in 1971 for the 15 per cent silver content alternative, and in 1974 if no silver were used in coinage. Details of this calculation are shown in Table B-10.

AVAILABILITY AND COST OF VARIOUS METALS CONSIDERED AS ALTERNATIVES TO SILVER IN COINAGE

Figure 1 shows the quantity of various metals that have been used each year since 1957 in the manufacture of U.S. coins. The increase in demand for copper and silver for U.S. coinage since 1959 is impressive. The amount of copper used in coinage is a relatively small proportion of the total production and consumption of the metal in the U.S., while the consumption of silver in U.S. coinage alone equals total world production. Thus, the criterion of availability is seen to be of paramount importance in the selection of an alternative material for coinage. If the currently available and potential capacity to produce a metal is insufficient to meet the present and projected needs for coins, it is pointless to use such a metal regardless of its technically desirable characteristics.

A large proportion of the known metallic elements were examined. These are listed in Table 2. This list contains all metals considered as remotely possible alternatives to silver. The initial selection or rejection of each metal was based on the criterion of availability and price.

Although the density of the present silver-base alloy is about 10.3 grams per cubic centimeter, the list includes elements that range in density from 1.7 for magnesium to 22.6 for osmium. Conceivably, high-density elements could be used as alloying elements to adjust the density of some possible low-density metal to about the desired value. Some of the elements are rather pointedly inappropriate for coinage. For example, mercury is a liquid at room temperature, and only a small number of alloys are possible. By law, gold cannot be used for coinage. The transuranium metals and rare-earth metals were not considered because of their extremely limited availability. Radioactivity, present in the uranium and transuranium elements, even in harmless amounts, would undoubtedly be a reason for low public acceptability of these metals as coinage. From the remaining elements, the following are rejected as possible coinage metals mainly because they do not meet the criterion of availability. Other pertinent reasons for rejection are also mentioned in the text.

Bismuth. There is no appreciable domestic supply. The metal has a low melting point, undesirable mechanical properties, a poor color, and world production is only about 4 million pounds.

Cadmium. This low-melting metal is in limited supply and has considerable strategic value. It is obtained mostly as a by-product of zinc production. The United States meets much of its requirements by importing.

Cobalt. Practically all of the supply of this metal is outside of the United States. For example, a large proportion comes from the Congo. In the event of a prolonged emergency, the supply could not be guaranteed. Cobalt could be considered as an alloying element, however.

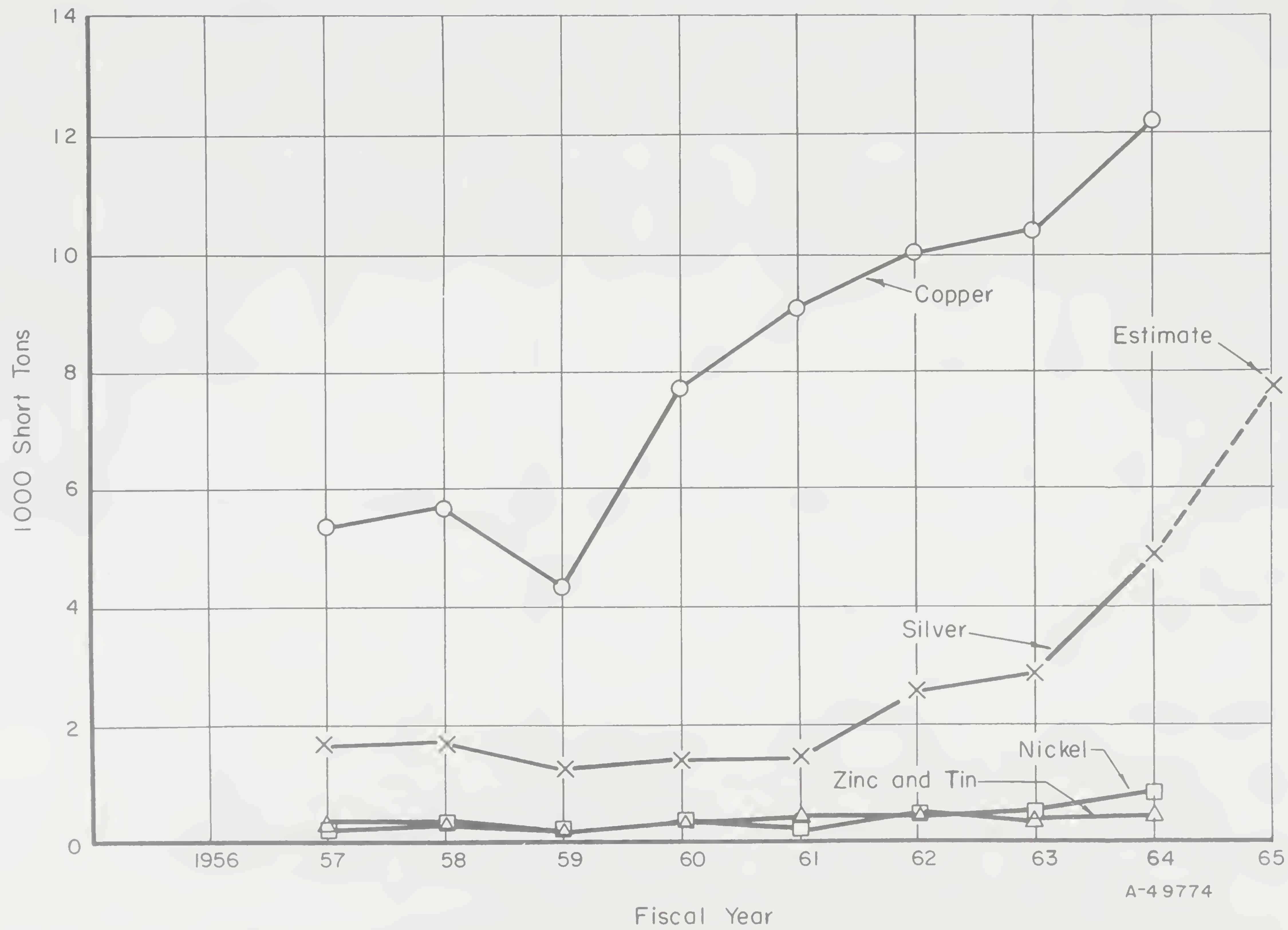

FIGURE 1. QUANTITY OF VARIOUS METALS USED IN UNITED STATES COINAGE

TABLE 2. METALLIC ELEMENTS CONSIDERED

Element	Density, g/cu cm	Melting Temperature, F
Aluminum	2.7	1200
Bismuth	9.8	520
Cadmium	8.6	610
Cobalt	8.8	2720
Chromium	7.2	3407
Columbium	8.6	4475
Copper	8.9	1980
Gold	19.3	1945
Hafnium	13.1	3900
Indium	7.3	315
Iridium	22.5	4370
Iron	7.8	2795
Lead	11.3	620
Manganese	7.4	2270
Mercury	13.5	-40
Molybdenum	10.2	4730
Magnesium	1.7	1205
Nickel	8.9	2645
Osmium	22.6	5430
Palladium	12.0	2825
Platinum	21.4	3215
Rhenium	21.0	5740
Rhodium	12.44	3560
Ruthenium	12.2	4080
Silver	10.5	1760
Tantalum	16.6	5425
Titanium	4.5	3035
Tungsten	19.3	6170
Uranium	19.1	2070
Vanadium	6.1	3435
Zinc	7.13	785
Zirconium	6.49	3365

<u>Hafnium</u>. Hafnium has a very high melting point (3900 F) and is produced as a by-product in the preparation of zirconium metal for nuclear-reactor purposes. The metallurgy is such that the cost of sheet and bar material is about $135 per pound. The bulk of the limited production of hafnium is allocated to nuclear-reactor use. It can be used only as an alloying addition.

<u>Indium</u>. This is a very soft metal (like lead) and has a low melting point. The price is high and the amount available is insignificant.

<u>Iridium</u>. A very costly metal of high density, iridium is available in the United States only in small amounts.

<u>Lead</u>. The metal is very soft, has a low melting point, and low strength. Lead has a "bad" name in reference to coinage because of associations with counterfeit coins.

<u>Magnesium</u>. This metal is very plentiful in the ocean. It is, however, extremely low in density (1.7 grams per cubic centimeter). The corrosion resistance is not good, especially when galvanic couples are present, such as magnesium in contact with copper. Its resistance to wear is low and it cannot be recommended for coin purposes.

<u>Osmium</u>. This metal is available only in very limited amounts and the price is very high.

<u>Palladium</u>. The price of palladium is higher than that of gold, and the quantities are very limited.

<u>Other Precious Metals: Platinum, Rhenium, Rhodium, Ruthenium</u>. Each of these metals is far too costly and scarce for consideration as coinage.

<u>Tantalum</u>. About 99 per cent of the tantalum ores processed in the U.S. are imported from the Eastern Hemisphere. The reserves are quite limited. The cost of sheet is currently about $50-$75 per pound. Its density is greater than that of lead.

<u>Vanadium</u>. This metal is difficult to prepare in high purity and has a high melting point (3435 F). It is used mostly as ferrovanadium (an iron-vanadium alloy) which is the principal source of vanadium for alloy steels. It has practically no use as the metal or as a base for alloying. The United States is a major world producer of this element but the cost of the metal in sheet and bar forms is presently about $40 per pound.

The metals remaining as candidate possibilities for coinage require more extensive appraisal from the standpoint of all important criteria. Certain of these metals may be considered very improbable if used alone, but they might be used as additions to alloys made up of two or more elements. This possibility is discussed below:

Chromium. Most of the available chromium ore is in the eastern hemisphere. The metal is generally classified as a strategic or critical material in the United States. The pure metal is difficult to prepare and is little used except as a thin-plating material. However, the availability of chromium as an alloying element appears firm enough to allow stainless steel to be definitely considered as a coinage metal. The supply-and-demand situation relative to this material is discussed more fully in Appendix A.

Columbium. Columbium metal, except as an alloying ingredient in cobalt alloys and steels has, until recent years, been considered mostly as a curiosity. Lately it has received some attention as a metal for high-temperature applications. Most of the high-grade ore is found outside the North American continent; but large amounts of low-grade ore occur in Canada (now being produced) and some in the United States. Very large low-grade deposits exist in South America, but much of the present production is from Africa. The production of the metal in 1964 was only about 25 to 30 tons. However, industry representatives estimate that the present production capacity could be increased to meet coinage needs within a period of about 2 years. The metal has some good qualities for coinage, such as excellent corrosion resistance, good coinability, and relatively high density (8.6 grams per cubic centimeter). Its color is gray but not unpleasant. The current price of columbium sheet and strip is higher than that of silver but this could be reduced as a higher rate of production reduced the cost. In spite of the price and present supply picture, the metal has a potential warranting further consideration.

Zirconium. The United States is believed to be self-sufficient in this metal, at least for foreseeable future needs. The present price is about $10-15 per pound for sheet. Most of this metal is now being used in nuclear-reactor applications.

The foregoing screening process indicates that the metals chromium, columbium, and possibly zirconium deserve further consideration either as minor alloying elements or for use in essentially the unalloyed condition for coinage. The metallic elements remaining after the preliminary screening process are:

Aluminum	Molybdenum
Chromium	Nickel
Columbium	Titanium
Copper	Tungsten
Iron	Zinc
Manganese	Zirconium

Of these metals, chromium, manganese, zinc, molybdenum, and tungsten are considered mainly as alloying elements. For example, the present one-cent coin contains an alloy addition of 5 per cent zinc. This quantity of zinc is small compared to the total supply and compared to the total amount consumed in the United States.

An appraisal of the supply and demand for each of these metals (with the exception of iron) is contained in Appendix A. This appendix includes data on the requirements and availability of each metal, covering the period from 1960 to the year 2000.

PHYSICAL, CHEMICAL, AND MECHANICAL PROPERTIES

A survey of the remaining 12 elements discussed in the foregoing section showed that, for the foreseeable future, the elements silver, chromium, manganese, molybdenum, and tungsten should be considered only for minor alloy additions with respect to coinage. The elements iron, copper, nickel, aluminum, columbium, titanium, zirconium, and various naturally occurring substances used in ceramics and plastics, should be given further consideration for use as the major constituents in United States coinage.* From these candidate raw materials, then, must be selected the alloy, pure metal, combination of metals, or nonmetallic materials which will serve as a substitute for the present 90 silver-10 copper alloy.

Before proceeding with the examination of possible substitute materials, it would be well to discuss certain properties of the present coin-silver alloy as well as the implications of these properties relative to the choice of a coinage material. This alloy, which has been standard in the United States for so many years, has a pleasing white color, is nonmagnetic, has a low electrical resistivity, and is relatively heavy. The original basis for the U. S. choice of silver for a coinage alloy seems natural enough in view of the long history of silver as a coinage metal and such desirable properties as ease of melting, rolling, and coining. That it is low in electrical resistivity and is nonmagnetic is fortuitous, since these properties provide a sensitive means of distinguishing this alloy from many other alloys that could be used to operate coin-actuated mechanisms. It is also interesting that the combination of white color, high density, low electrical resistivity, and absence of magnetism is unique to the silver-copper alloy system. Moreover, the alloys are easy to process in the Mints. No other element or alloy has this particular combination of properties.

Physical Properties Needed in Coinage for Coin-Operated Mechanisms

With coinage unchanged in size and alloy over so many years, industries based on coin-operated mechanisms have had a chance to develop and grow.** Important to these industries has been the invention of coin selectors capable of detecting slugs on the basis of electrical conductivity, density, size, and magnetic characteristics.

Permanent magnets play an important role in these selectors. They remove magnetic coins and slugs and are the heart of the eddy-current device that separates coins and slugs according to a property represented by the product of electrical resistivity and density. This product, for the coin-silver alloy, is about 21.6 microhm-g/square centimeter, while for the 5-cent piece it is about 286. The eddy-current type of coin selector is adjusted to accept genuine silver coins and to reject copper and many of its alloys, including brasses such as the 90-10 copper-zinc alloy.

If no changes are to be required of industries which use coin-operated devices, the physical properties of a substitute material must be specified in such a way as to make the behavior of the new material identical with present coinage in coin-operated mechanisms.

*Magnesium is available in almost unlimited amounts from the ocean but is eliminated from consideration as a coinage material because of its extreme lightness and poor corrosion resistance.
**See Appendix C, Coin-Operated Devices.

Color

The choice of color for U. S. coinage is largely a matter of public acceptance. Traditionally, the U. S. subsidiary coinage has been silvery-white. Suggested alloys should be considered from this standpoint.

Just as white has been associated with subsidiary coinage, copper-red has been associated with minor coins both here and abroad. Accordingly, it would seem inadvisable to substitute a red alloy for our present coin silver.

Shades of yellow from the typical brass to a reddish-golden color may be more acceptable than red coins because of the association with gold.

It is difficult to make a categorical statement of public reaction to any change. It is believed, however, that strong preference would be voiced for white alloys over any yellow or red alloy.

In the long-range picture, in which plastics or ceramics might be considered, very distinctive colors could be deliberately chosen as an anti-counterfeiting measure. Such a possibility must be considered quite drastic, however.

Candidate Materials Considered From the Viewpoints of Coin-Operated Mechanisms and Color

A substantial number of metals and alloys can be suggested as candidates for replacing the present coin silver. In addition, another kind of material, called a "composite", has been considered. Appendix C, Coin-Operated Devices, treats this subject in some detail.

When certain desirable properties cannot be realized with a homogeneous material, they can often be met in composite systems. In composite systems two or more materials, each unable to satisfy all the requirements, are combined in such a way that the over-all behavior of the composite is satisfactory. One such composite is called a "multilayer material", wherein the components are bonded together in sandwich fashion in such combinations as to obtain the properties needed. Notable examples of multilayer metal systems are the bimetallic thermostat alloys, the stainless-clad copper pots and pans, and precious-metal-clad plate for watch cases. Similarly, a multilayer system for coinage material can be assembled as illustrated in Figure 2. With the proper proportion of a high-conductivity metal (which can be either the core or the cladding), composites can be bonded, rolled into strip, blanked, and stamped into coins which will behave in the coin selectors in the same way as the current silver-alloy coins. Some of the composite or multilayer systems considered for coinage purposes are the following:

- Cupronickel (75 Cu-25 Ni) clad over pure copper
- Cupronickel clad over various silver-copper alloys
- Silver-copper alloys clad over cupronickel
- Silver-copper alloys clad over modified coppers
- High silver-copper alloys clad over low silver-copper alloys.

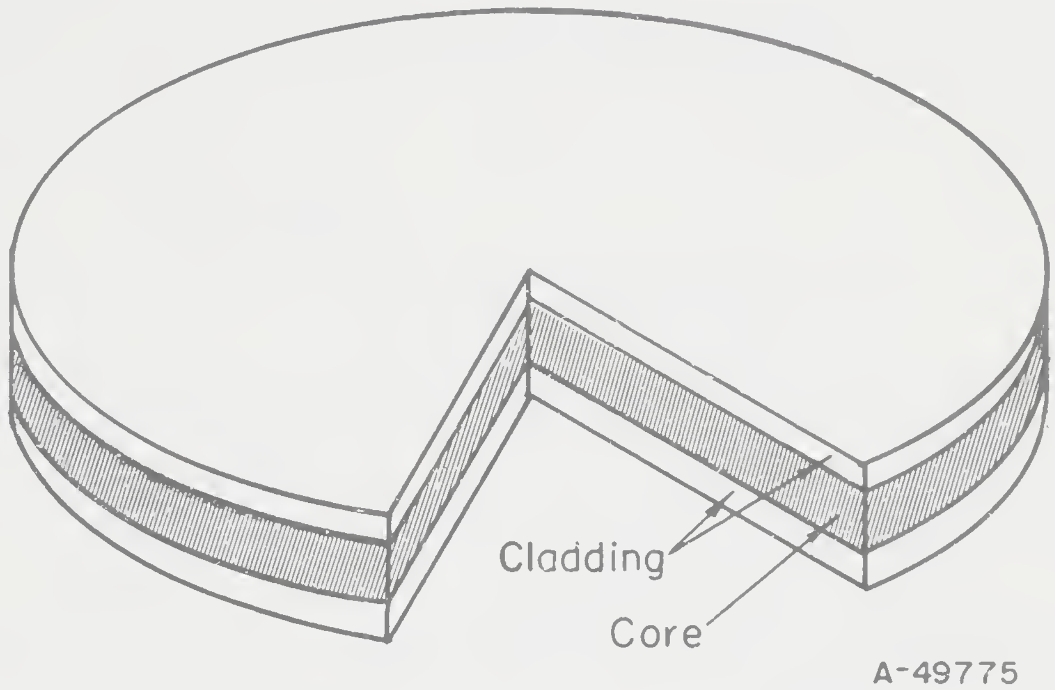

FIGURE 2. MULTILAYER COMPOSITE COIN BLANK

Each of the composite materials listed has outer layers consisting of an alloy with a white color. Thus, it can be seen that numerous different composites can be devised that can satisfy both the public-acceptance criterion of color and the requirements of coin-operated devices as regards low electrical resistivity (or better, the correct product of electrical resistivity x density).

There are other possible candidate metals and alloys that might satisfy the criteria for coinage except that they would not be compatible with present coinage in coin-operated mechanisms. Still another group of metals enters the picture if the public would accept a copper-colored coin.

Table 3 lists a number of candidate materials. The arrangement and classification of the materials in this table are designed to separate and emphasize the choices with regard to the criteria of color (public acceptability) and usability in coin-operated mechanisms. The arrangement in Table 3 thus emphasizes some conflicting requirements that a coinage alloy must satisfy. For example, if a white color is desired regardless of the resistivity x density product or magnetic properties, then a rather large number of possibilities exist. If, on the other hand, a white color is desired, combined with a resistivity x density product satisfactory for coin-operated devices, there are only a few possibilities. Lastly, if a reddish color were acceptable, a number of copper-base alloys are available which could also be made to work in coin-operated devices.

Appendix C discusses the various candidates from the viewpoints presented in Table 3. If it is desired for coin-operated devices to continue in operation without modifications, and if a white color is required for public acceptance, the following two appear to be the best choices:

TABLE 3. CANDIDATE MATERIALS FROM THE VIEWPOINTS OF CERTAIN PHYSICAL PROPERTIES

<table>
<tr><td colspan="2">Require Changes in Coin-Operated Devices</td><td colspan="2">Do Not Require Changes in Coin-Operated Devices</td></tr>
<tr><td colspan="3">White</td><td>Red</td></tr>
<tr><td colspan="2">Resistivity x Density Too High or Too Low</td><td colspan="2">Resistivity x Density Satisfactory[a]</td></tr>
<tr><td>Magnetic</td><td colspan="3">Nonmagnetic</td></tr>
<tr><td></td><td>Resistivity x Density Too High</td><td></td><td></td></tr>
<tr><td>Nickel</td><td>Cupronickels</td><td>Modified silver alloys</td><td>Copper modified by the addition of nickel, zinc, phosphorus, etc.[b]</td></tr>
<tr><td>Chromium-stainless steels</td><td>Nickel silvers (copper-nickel-zinc alloys)</td><td>Silver-copper alloys</td><td></td></tr>
<tr><td>Irons</td><td>Columbium</td><td>Multilayer composites</td><td></td></tr>
<tr><td></td><td>Nickel-5 silicon</td><td>Plated coppers</td><td></td></tr>
<tr><td></td><td>Chromium-nickel stainless steels</td><td>Certain aluminum alloys[a]</td><td>Copper[c]</td></tr>
<tr><td></td><td>Nickel-chromium</td><td></td><td></td></tr>
<tr><td></td><td>Monel</td><td></td><td></td></tr>
<tr><td></td><td>Titanium</td><td></td><td></td></tr>
<tr><td></td><td>Zirconium</td><td></td><td></td></tr>
<tr><td></td><td>Ceramics</td><td></td><td></td></tr>
<tr><td></td><td>Plastics</td><td></td><td></td></tr>
<tr><td></td><td>Resistivity x Density Too Low</td><td></td><td></td></tr>
<tr><td></td><td>Silver</td><td></td><td></td></tr>
<tr><td></td><td>Aluminum</td><td></td><td></td></tr>
<tr><td></td><td>Most aluminum alloys</td><td></td><td></td></tr>
</table>

(a) Low density precludes the use of aluminum alloys in many devices that are actuated by the weight of the coin.
(b) The modifications would be small additions intended to raise the resistivity of copper only a small amount.
(c) Not all coin-operated devices will accept copper.

- Silver-copper alloys (depending on the silver supply picture)

- Various multilayer composites such as cupronickel-clad copper.

If modification of present coin-operated devices is permissible, a wide variety of materials is available to choose from. Nevertheless, the nonmagnetic materials would be preferable to the magnetic ones, in order to minimize the disruption in the use of coin-operated devices. Lightweight materials such as aluminum alloys, plastics, and ceramics would cause more disruption in the use of coin-operated machines than would other materials.

Consideration of Mechanical and Chemical Properties

The mechanical properties of the candidates must be such as to insure wear resistance and resistance to normal handling procedures. Nevertheless, the strength characteristics must not be so high as to prevent coining. The corrosion resistance must be high enough to insure good appearance over a long time period.

For the candidates listed in Table 3, the modified coppers may be too soft to permit their use, though if nickel, zinc, aluminum or silicon are the modifiers, it is possible to obtain satisfactory strength and hardness. The durability of ceramics (with respect to shattering) needs further study. The coinability of certain of the materials is very limited; notable in this respect are most stainless steels, monel, and titanium. These aspects are discussed in the section Mint Operations and Their Relationship to Alternative Coinage Materials.

The corrosion resistance of many aluminum alloys is not outstanding. This factor, along with low density, excludes aluminum alloys from further consideration.

MINT OPERATIONS AND THEIR RELATIONSHIP TO ALTERNATIVE COINAGE MATERIALS

Any material taking the place of the current silver coinage alloy must be capable of being handled by the Mints. It is essential that the material be adaptable to the present Mint facilities, especially with regard to coinability. Other considerations include upsetting (edge rolling), strip rolling, and melting. A discussion of the United States Mint facilities is given in Appendix D.

Coinability

Coinability refers to the ability of the coinage material to take a sharp, clear impression, of the proper depth and design, when the preformed blank is pressed between two dies. It is also important that the material possess good coinability under conditions of high-speed coining, without excessive die pressures.

From the standpoint of coinability, based on experience and actual Mint trials of a number of possible substitute coinage metals, the following materials are judged to be acceptable, with little or no change in processing methods. Appendix D summarizes the experimental work:

(a) Cupronickel (75Cu-25Ni)

(b) Pure nickel

(c) Columbium

(d) Multilayer or composite material using combinations of cupronickel, copper, and silver

(e) Silver-copper alloys in all proportions

(f) Nickel-5 silicon alloy (requires a change in annealing procedure).

Those metals and alloys judged to have lower coinability than the above group were:

(a) Stainless steels (both straight-chromium types and austenitic chromium-nickel types)*

(b) Zirconium

(c) Titanium

(d) Nickel-chromium alloys.

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* A stainless steel recently developed by Republic Steel Company shows promise for better coinability than any of the currently available stainless steel. This new steel has not been fully evaluated at the present time, however.

A process change, such as the addition of an annealing treatment, or a change in design of the coining dies, might permit some of the questionable materials to be successfully coined. However, a die design change is not always desirable from the point of view of counterfeiting and illegal duplication, which are discussed later.

Upsetting

The upsetting operation is often termed "edge rolling"; its purpose is to thicken the edge or rim of the blank prior to coining. This is done to provide sufficient metal at the edge for the coined blank to develop a rim greater in height than the rest of the coin. This provides wear protection to the coin and also allows coins to be stacked evenly.

Mint coining experiments described in Appendix D showed that some problems exist with certain materials during this processing step. For example, the nickel-5 silicon alloy and the stainless steels work hardened to an appreciable extent during edge rolling. The surfaces of the coin blanks near the edge tended to become hardened. This, in turn, led to difficulty when the blanks were coined. The cold-worked areas adjacent to the rim did not flow sufficiently in the coining die, and the lettering at this location did not fill out properly. In a case such as this, the annealing treatment ordinarily given the blanks before upsetting could be given instead to the upset blanks.

Some buckling of the blanks occurred during upsetting of the copper-cored multilayer composite materials because of the softness of the core. Possibly, some adjustments in the blank annealing treatment would be necessary to overcome these difficulties, or, as suggested in the preceding paragraph, the annealing operation could be deferred until the blank was upset.

Rolling and Annealing

Essentially, the Mints are presently limited in rolling capabilities to those of a brass mill and, at present, they are equipped to do only cold rolling with intermediate annealing in controlled-atmosphere furnaces. Except for such metals as zirconium, titanium, and columbium (which require vacuum annealing), the Mints could probably cold roll most of the other possible substitute alloys such as monel, stainless steel, and certain composite materials. However, for anything other than copper-nickel, silver-copper, or copper-base alloys, additional annealing facilities would be required. Rolling of the 50 silver-50 copper alloy may require more annealing than will the 90 silver-10 copper alloy.

To handle the rolling of such metals as columbium, titanium, and zirconium, the Mints would require high-temperature vacuum-annealing equipment. It would probably be necessary to hot roll (1500-2000 F) columbium to break down the ingot structure. This, in turn, would require conditioning to remove the contaminated surface layers from the breakdown product. The metal cold rolls easily, however.

Melting

Melting capabilities of the Mints are equivalent to those of a brass mill. Consequently, to melt such materials as nickel (also high-nickel alloys), stainless steels,

and similar metals, a change in linings for the induction-melting equipment would be required. The melting procedure and probably the casting technique would also require changes to handle these metals and alloys properly. The melting of metals such as columbium, zirconium, and titanium requires special consumable-arc melting equipment. This would mean a considerable capital investment for the equipment and related power supply and controls. Columbium, which deserves special consideration because it coins very well, would, for the present, have to be melted and rolled by an outside producer and be supplied to the Mints in coils for blanking and coining.

Additional Operations

Certain alloys or metals will require a supplemental treatment to improve the appearance of the coin. Thus, for example, the 50 silver-50 copper alloy takes on a yellowish color during processing. The coin blank can be brightened to a silvery-white color by dipping in a nitric acid solution. Similarly, zirconium can be brightened by dipping in a mixture of hydrofluoric and nitric acids. The Mints are not now equipped for such processes, however.

Conclusions

From the standpoint of Mint operations, the following conclusions apply:

(1) If the total Mint facilities from melting to coining are to be involved, the following substitute coinage materials would not require any changes in present operations:

- Cupronickel
- Copper-base alloys
- 50 silver-50 copper alloy

(2) If rolling, blanking, and coining only are to be involved, the acceptable substitute coin materials include, in addition to those listed in (1):

- Nickel, nickel-5 silicon
- Multilayer composite materials

(3) If strip were purchased and blanked and coined by the Mints, the following additional materials would be acceptable:

- Columbium
- Multilayer composites [see also (2) above]

(4) Materials not acceptable or questionable (especially as relates to coining) for the present Mint facilities, are:

- Stainless steels
- Nickel-chromium alloys
- Titanium
- Zirconium

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POSSIBLE CHOICES OF MATERIALS FOR U. S. COINAGE

When all the various criteria have been applied to the possible candidate materials for coinage, it is found that no single material satisfies all of the criteria. Several of the candidate materials possess certain desirable characteristics not possessed by others. Specifically, the following materials have been selected because they have certain advantages over each of the others. They are discussed further in the paragraphs that follow:

1. Silver-copper alloys, particularly 50 silver-50 copper.

2. Cupronickels, particularly 75 copper-25 nickel.

3. Copper-nickel-zinc alloys (nickel silvers).

4. Columbium and zirconium.

5. Multilayer composites.

    a. cupronickels on copper
    b. silver-copper alloys on copper
    c. high silver-copper alloys on low silver-copper alloys
    d. silver-copper alloys on cupronickel and vice versa

6. Nickel and high-nickel alloys.

These materials are discussed further below.

Silver-Copper Alloys

The principal advantages of silver-copper alloys are that such alloys have a high degree of public acceptance because of a long history of use as coinage; they are relatively easy to process in the Mints; and their use would require no changes in present coin-operated devices.

The most serious disadvantage of any silver-copper alloys is that they do not satisfy the criterion of supply and price. As shown in Appendix B, any plan for long-term use of silver for coinage must be considered as questionable; the supply and price is assured only as long as the Treasury stocks are able to supply silver for this purpose. Nevertheless, if sentiment and tradition are considered to be compelling reasons for using a silver-copper alloy, then it would seem prudent to limit the silver content to 50 per cent, and to use the alloy for only one denomination of coin. In this way the overall consumption of silver would be about 16-17 per cent of the normal consumption and might permit the Treasury stocks to last for perhaps 10 to 15 years, depending on the coinage demand and speculation.

A further difficulty with a silver-copper alloy containing less than about 70 per cent silver is that the tarnish resistance is markedly lower than that of the present

90 silver-10 copper alloy. An acid dip would be required to give the coin a good appearance when newly minted, although it would tarnish in use. A solution to the tarnish problem can be achieved by using a sandwich-type of material with a high silver alloy for the outer layers and a low silver alloy as the core. These possibilities are discussed below, in the section Multilayer Composites.

Cupronickels

The term "cupronickel" applies to a series of alloys of copper and nickel in which copper is the major element. Because of the Mint's familiarity with the 75 copper-25 nickel composition, however, this particular alloy has been singled out for special attention. The chief advantage in using the 75 copper-25 nickel alloy for subsidiary coinage would be that the Mints could make the conversion with little or no disruption in their processing methods. Also, its wear resistance is superior to the present silver alloy.

Among the objections to the alloy is that it is low in cost and would invite illegal duplication and slugging. However, the main difficulty is that a large proportion of the coin-operated machines would require changeover to be able to accept both the present coinage and the new coinage.

The color of the 75 copper-25 nickel alloy is pleasing, though not as white as coin silver. Copper-nickel alloys containing about 45 per cent nickel are much whiter than the 75-25 alloy. However, because of higher melting and annealing temperatures, some change in Mint procedures would be necessary. Thus, the chief advantage to cupronickels would be lost, without a significant reduction in the disadvantages. Therefore, it is judged that if a cupronickel is chosen it should be the 75 copper-25 nickel alloy.

Copper-Nickel-Zinc Alloys (Nickel Silvers)

Because copper-nickel-zinc alloys can be made with only minor adjustments in Mint processing, the white alloys (typified by the 65 copper-18 nickel-17 zinc composition) may be considered as alternatives to the cupronickels. In general, the advantages and disadvantages are the same as for the 75 copper-25 nickel alloy. However, the cost of the raw materials would be somewhat lower than for the cupronickels. On the other hand, this cost advantage would be offset in part by the need for somewhat more complicated Mint processing methods. Ease of changeover in the Mints gives the cupronickel preference over the nickel silvers for subsidiary coinage. However, if the subsidiary coinage is changed to cupronickel, the alloy for the five-cent coin might well be changed to a copper-nickel-zinc alloy so as to distinguish between low- and high-value coins. If the difficulties of Mint changeover are not regarded as decisive, nickel silver could be used for subsidiary coinage.

Columbium and Zirconium

The metallic elements columbium and zirconium are worthy of consideration because they have the advantage of being difficult (though not impossible) to counterfeit, and so high in price as to virtually eliminate illegal duplication.

Columbium proved to have good coinability. The use of zirconium, however, would require some modification in die design or coining methods in order to yield satisfactory coins. The somewhat poorer coinability of zirconium is partially compensated for by a good ore supply picture, although metal-production capacity would have to be increased.

Processing of columbium and zirconium is so significantly different from current Mint practices that it would be preferable to purchase strip from outside suppliers.

Adoption of columbium or zirconium would require changes in coin-operated devices similar to those required for cupronickel.

However, the advantages of high resistance of columbium or zirconium to counterfeiting and illegal duplication must be weighed against the ease of adapting cupronickel to Mint procedures.

In view of this reasoning, it is believed that the over-all costs of adopting cupronickel, columbium, or zirconium should be compared. This comparison shows that the increased cost of adopting either columbium or zirconium would be in the order of \$100,000,000 annually, based on a comsumption of 10,000,000 pounds per year. This seems to be a high price to pay for preventing counterfeiting or illegal duplication.

Neither columbium nor zirconium have prestige value, in the sense that silver has. Columbium and zirconium, however, do possess certain characteristics - high price, attractive name, and application in the atomic energy industry - that lend themselves to the creation of a desirable "public image". A vigorous public relations campaign would be needed to achieve this end.

In balance, however, the advantages seem overweighed by the disadvantages. Therefore, no further consideration will be given to columbium or zirconium.

Multilayer Composites

The multilayer composites (also called "clad metals" or "sandwich metals") have received attention as materials which can be used to produce a coin with almost the same appearance as the present coinage, capable of acceptance in present coin-operated devices, and yet containing either no silver at all or a drastically reduced amount of silver. The uniqueness of multilayer composites would discourage both counterfeiting and illegal duplication, while, at the same time, the cost of production would be moderate.

Processing, for a time, would be outside of the Mints' capabilities. However, various methods for producing multilayers have been developed in industry, and it is believed that Mint processes could be adapted to the manufacture of multilayer composites without serious difficulties. The Mint could purchase strip or re-roll bar from outside suppliers until its own skills have been developed. While the characteristics of the multilayer composites to be discussed have been established on an experimental basis during the course of this study, feasibility for full-scale Mint operations remains to be determined. Furthermore, it would be necessary for the Mint to have assured sources of supply until it developed its own capability to produce any multilayer that might be chosen as a coinage material.

The characteristics of various combinations of multilayers are discussed below.

Cupronickel on Copper

Of the various choices of multilayer, cupronickel on copper possesses the advantages of low cost and good scrap value, in addition to the general advantages previously noted for cupronickel. Scrap must be taken into account because about 30 per cent of the strip remains as a skeleton after the coin blanks have been punched out. Scrap from the cupronickel-copper combination, since it consists only of copper and nickel, could be utilized to make more cupronickel simply by adding proportionally more nickel to the charge material in the melting furnace.

A feature of this combination is that the exposed edge of the coin is copper colored. This has the advantage of being difficult to counterfeit or duplicate. On the other hand, the appearance would be distinctly different from traditional U. S. coins and might cause some problems relative to public acceptance.

High Silver-Copper Alloys on Copper

A sandwich consisting of a silver-copper alloy on copper has the advantage of providing a coin close in appearance, except for the copper rim, to the present coins. It would have a better appearance than the cupronickel-copper composite. Moreover, it would have higher intrinsic value than the cupronickel-copper composite.

Scrap could be reclaimed by using it to make the silver-copper alloy cladding.

The primary disadvantage, as pointed out in connection with silver-copper alloys, is that continued use in coinage would be limited because of the silver supply situation.

High Silver-Copper Alloys on
Low Silver-Copper Alloys

If the red rim on the copper-cored composites is objectionable, it can be eliminated by using a low silver-copper alloy for the core. For example, a possible combination is to have 80 silver-20 copper for the outside layers and 30 silver-70 copper for the core. Such a coin would be close in appearance to present coins. Though the rim would tarnish, it might be preferable to the copper color.

Supply of silver is again the main obstacle to adoption of such a combination.

Silver-Copper Alloys on Cupronickel,
and Vice Versa

Another means of obtaining a "white-on-white" combination is by cladding cupronickel with, say, an 80 silver-20 copper alloy. The principal disadvantage to this combination is that the scrap would have to be reclaimed by separation of the elements, rather than by remelting, because it would consist of copper, nickel, and silver.

Furthermore, as the high-conductivity silver-copper alloy wore off the faces, the response of the coin to the eddy-current coin selectors would change markedly. The reverse combination, cupronickel on a silver-copper alloy, would not be susceptible to this disadvantage. However, it would not have the close resemblance to the present coinage which the silver-copper on cupronickel would have.

There seem to be sufficient deficiencies in this approach to drop it in favor of the other multilayers discussed above.

Nickel and High-Nickel Alloys

Nickel has enjoyed considerable usage in other countries as coinage. It is considered here because of its relatively good appearance, corrosion resistance, and coinability.

Because nickel is magnetic, however, almost every type of coin-operated device would have to be altered if it were adopted for coinage. For this reason alone, it cannot remain as a strong candidate for U. S. coinage.

Other materials, though not presently acceptable, would require certain changes to be made in most machines, but not in all. Cupronickel has been discussed in this light. Other such possibilities are nickel-base alloys containing alloying agents that cause the magnetism of nickel to disappear. Nickel-5 silicon, developed by the International Nickel Company, is an example of such an alloy.

The main advantages advanced for these types of alloys is that they are as highly regarded as nickel, which is accepted in many countries. It cannot be argued, however, that their high regard is in any way comparable to the regard for silver. Compared to the cupronickels, they are somewhat brighter in appearance, but their cost is higher and the amenability to Mint processing is lower. Therefore, it is judged that the high nickel alloys should be dropped from further consideration.

Attention is also called to a nickel-5 silicon alloy with a magnet material in the center of the coins. This composite, discussed in Appendix C, was developed by the International Nickel Company as a means of operating the present coin selectors in coin-operated devices. The reasons for dropping this composite from further consideration are given in Appendix C.

PRELIMINARY EVALUATION OF MATERIALS FOR SUBSIDIARY COINS

Summary of the Chief Advantages and Limitations of Various Canadidates

The previous section indicated that three types of materials stand out above all others for one or more reasons. These three are:

- 50 silver-50 copper alloy
- 75 copper-25 nickel alloy (and the closely similar 65 copper-18 nickel-17 zinc alloy)
- multilayer composite with a core of either copper or a low silver-copper alloy

Each of these three kinds of materials is outstanding in at least one respect, but each fails to fully satisfy at least one of the criteria upon which a selection should be based. The desirable and undesirable aspects of the various choices are recapitulated below:

Material	Main Advantages	Main Limitations
50 silver-50 copper	• Maintains tradition of silver in coinage • Acceptable in present coin-operated devices • Minor effect on Mint processes • Low counterfeit or duplication potential	• Limited by the supply of silver • Much lower tarnish resistance than present coins • High price
75 copper-25 nickel	• Practically no effect on Mint processes • Low price • Good wear qualities	• Not acceptable in present coin-operated devices • Potential for illegal duplication
Multilayer Composite: 75 copper-25 nickel on copper	• Acceptable in present coin-operated devices • Difficult to counterfeit or duplicate • Moderate price	• Requires purchase of material until Mint acquires the necessary skills to manufacture it • Copper colored outer rim is a departure from the appearance of present coins.
80 silver-20 copper on copper	• Much the same as 75 copper-25 nickel on copper, but faces are the same color as present coins	• Same as above, but limited by the silver supply
High silver-copper alloy on low silver-copper alloy	• Same as 80 silver-20 copper on copper, but would have no copper colored rim • Maintains the tradition of silver in coinage	• Limited by the silver supply • Requires purchase of materials until the Mint acquires the necessary skills to manufacture it • High price

In terms of the criteria for coinage, the above array of the pros and cons of each material suggests that weights must be assigned to the importance of maintaining a tradition of silver in the coinage, effect on Mint processes, and acceptability to coin-operated devices.

The importance of tradition must be balanced against the silver supply, which will determine how much total silver can be used. The problem of changeover by the vending machine industry, multilayer composites, and Mint processes should be considered together because they are closely related. In the sections that follow, these problems are discussed from the viewpoint of the over-all consequences of various changes.

Limitations on the Use of Silver in Coinage

The use of silver in coinage has had a long tradition in this country and in the rest of the world. Nevertheless, the analysis of the silver supply-and-demand situation indicates that the Treasury stocks cannot last indefinitely. When the Treasury stocks have been exhausted, if silver is still a component of coinage, the Government would have to purchase silver on the open market, competing with industry for what is likely to have become a scarce commodity. Eventually, the pressures of important industrial and defense needs will probably compel the Government to abandon silver altogether. Hence, if the presently contemplated legislation regarding the composition of coinage is to be of a very long-term nature, silver should not be included in the recommended compositions.

Despite the apparent inappropriateness of considering silver as part of the long-term solution to the coinage problem, public sentiment and tradition may call for something less than total abandonment of silver at this time. In such a case, the rate of silver consumption in coinage must be selected so as to take into account the fact that the Treasury stocks are the main deterrent to a rise in the price of silver.

By preventing a rise in the price of silver, the Treasury stocks help prevent the melt down of the coinage now in circulation. For the Treasury stocks to be effective in this role, the following condition should be satisfied:

> The rate of reduction of the Treasury stock should be so low that there would be little current incentive for speculative hoarding in anticipation of a price rise when the stock has run out. Ten years' life for the stock seems adequate for this purpose.

If the public could be assured that there would be no price rise for a long time to come, there would be less likelihood that the present coinage would be withdrawn for speculative reasons. Withdrawal of coins from circulation for sentimental and numismatic reasons probably would also be slowed up under these circumstances, so that Mint production might be able to meet the total demand for coins more readily.

What must the silver content of the coins be to achieve this end? According to Table 1, a silver content of 15 per cent in all coins would permit the stocks to maintain the price of silver for a period of perhaps 10 to 15 years depending on the level of coinage demand. To maintain an over-all silver content of 30 per cent would reduce the stocks to zero by the years 1971-1977, depending on the coinage demand. Paradoxically,

since it would be possible to foresee a rise in the price of silver in only 6 years if the demand were high, it is likely that high demand would be created by the incentive for speculative hoarding. Thus, the adoption of as much as 30 per cent silver in the coinage system might make it difficult to keep the present coinage in circulation. Moreover, Mint capacity would not be so high as to be able to cope with the ensuing shortage.

It thus seems that the upper limit of silver in the total coinage composition should be 15 per cent. As indicated earlier, this over-all percentage can be achieved in a number of ways, which are discussed later. Some caution must be excercised in choosing the 15 per cent silver level, because, as Table B-10 (Appendix B) shows, high industrial demand could cause depletion of the Treasury stocks by 1971.

ALTERNATIVE CHOICES FOR VARIOUS DENOMINATIONS OF COIN

Possible Ways in Which Some Silver Might be Retained in the Coinage

In the previous section, it was indicated that the total annual consumption of silver for coinage should be limited to an amount that would be equivalent to that consumed if an alloy containing 15 per cent silver were used in all subsidiary coins. Since an alloy containing 15 per cent silver is not advisable, because of unattractive color and low tarnish resistance, other ways of achieving this consumption rate have been considered.

For example, if only one coin were made of a silver alloy, the alloy could be quite high in silver content and yet not exceed the supply limitations. Since silver is being considered chiefly on the basis of tradition and the prestige it leads to the coinage system, it would seem appropriate to select the half dollar rather than the dime or quarter as the silver coin.*

The alloy selected for the half-dollar coin would depend on the number of half dollars minted. Thus, if 30 per cent of all subsidiary coins were half dollars (on a face-value basis), the silver content of the coins could be 50 per cent. If the half-dollar were to make up only 18.7 per cent of the face value of all subsidiary coins minted, the silver content of the coins could be as high as 80 per cent.

Because the tarnish resistance of the 50 silver-50 copper alloy is low, the 80 per cent alloy would be preferred. This would necessitate fixing the number of half-dollars coined each year. In the past, the percentage of half-dollars minted has not been constant from year to year. In 1962, 1963, and 1964, about 24, 31, and 36 per cent, respectively, of the value of all subsidiary coins was in half dollars. The median value since 1950 was 23 per cent. Therefore, production would have to be limited if a high silver alloy were adopted for the half dollar.

Another possibility would be to spread the available amount of silver evenly through all the subsidiary denominations. This could be done with a multilayer composite. For example, if the outer layers of the composite contained 40 per cent silver, and the core were essentially copper, the over-all silver content could be maintained at 16 per cent. Such a combination could be used in all coin denominations and still be within the limitations placed on silver consumption.

If the outer layers of the composite consisted of an alloy containing only 40 per cent silver, the tarnish resistance would again create a serious problem. One way of improving the color and tarnish resistance somewhat is to add a small amount of zinc and nickel. Though not nearly so good as present coin silver in this respect, the alloy might possibly meet minimum standards of acceptable appearance. Appendix C points out that an alloy consisting of 40 silver-50 copper-5 nickel-5 zinc is used for coinage in

*The consideration of alloys for the silver dollar is outside the scope of the present study. However, it is believed that, were silver dollars to be minted in amounts of 35 million pieces or less per year, they would not serve as a medium of exchange at the present time, but would be hoarded. On the other hand, if silver were removed from all subsidiary coinage, it might be desirable to begin minting silver dollars after sufficient time had elapsed to permit some relaxation of the protection afforded by the Treasury itself.

Sweden, but that its electrical resistivity is too high to make it acceptable in eddy-current coin selectors. However, if the core of the composite were copper, the combination would have an acceptable resistivity x density product. Though the alloy would not be as easily processed to strip (prior to cladding) as is the 90 silver-10 copper alloy, its processing should not represent a great departure from present practice. More details regarding this multilayer composite are given in Appendix C.

Cupronickel and Multilayer Composites

In the comparison of materials from various points of view, it is seen that the cupronickel alloy has the advantage of being able to fit into the present Mint operations with a minimum of disruption. A changeover to cupronickel could be handled quickly and smoothly. On the other hand, to modify coin-operated devices to accept cupronickel would probably require several years to complete. Industry estimates have ranged from 2 to 10 years for this change.

The composite materials, on the other hand, would cause no disruption to the industries concerned with coin-operated devices. However, because the manufacture of composite strip is presently outside of the Mints' capabilities, the strip would have to be purchased.

The costs of conversion of the coin-operated devices and increased losses due to slugging should be compared with the premium paid for multilayer composites. It is difficult to estimate the cost of conversion, because there are three elements involved. The first element is the direct expenditure of funds by the operators of the machines to replace or modify the mechanisms. Estimates of the cost have ranged from \$12,000,000 to \$100,000,000 for the vending industry. The second element is the loss of business resulting from the inability of the new coins to operate a vending machine that has not been changed over. There have been no data obtained that can provide a basis for estimating these losses. On a yearly gross sales volume of \$4 billion, however, even a 5 per cent loss in gross sales is \$200,000,000. Vending-industry figures indicate slightly higher than 4 per cent profit on gross sales. Thus, a 5 per cent loss of business per year during the changeover would amount to a loss of \$8,000,000 in profit annually. Even higher losses would be expected if the present coinage did not remain in circulation. The third element in the costs of adopting cupronickel is the probable increase in losses due to slugging as long as the silver coins had to be accepted. No estimate of this increase can be made at present.

It is estimated that the additional cost to the Mint of purchasing the multilayer strip would be between 40 and 70 cents per pound. In normal years, this would amount to about \$5,000,000 per year. At current production rate it would amount to as much as \$10,000,000.

In the over-all weighing of the costs, it should be noted that the changeover costs would be temporary, while the losses due to slugging and the costs of purchasing strip would be annual costs. While no estimate of increased slugging losses has been made, it seems reasonable to suppose that these losses would be on the same order of magnitude of the increased costs of purchasing strip. Therefore, it would seem that the choice of a multilayer composite would cause less over-all inconvenience and monetary losses than would the cupronickel.

From the point of view of the Mint, an immediate changeover could be made, in a sense, by returning to the manufacture of strip for 1-cent and 5-cent coins (which is now purchased) and purchasing material for the 10-, 25-, and 50-cent coins (which is now manufactured by the Mints).

Other Considerations in Adopting Multilayer Composites

Wear

Measurements of dimes, quarters, and five-cent pieces now in circulation indicate that to insure a 30-year life for the coin before the core would show through, the clad thickness should be no less than 0.0075 inch on the dime in either the cupronickel or the silver alloy, and no less than 0.010 inch on the quarter. This minimum will permit a small amount of cladding to remain and still permit the coin to function in the eddy-current type selectors. Fortuitously, the clad thickness increases during the coining process at the highest parts of the coin, which would be subject to the greatest amount of wear. Figure 3 illustrates this fact. It shows the cross section of an experimental dime and quarter made of a cupronickel on a copper core.

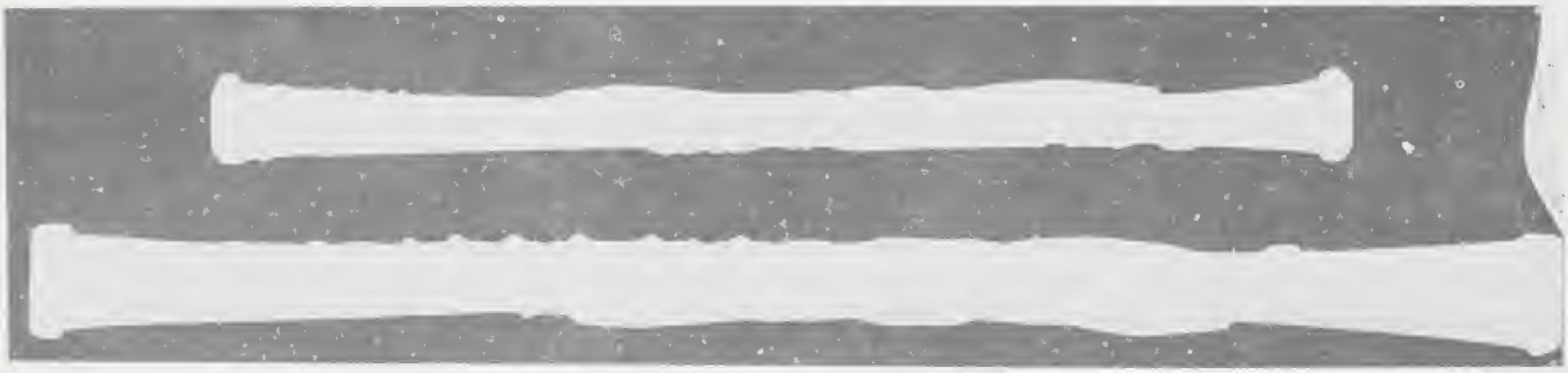

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FIGURE 3. MAGNIFIED CROSS SECTION OF DIME (TOP) AND QUARTER (BOTTOM) MADE FROM CUPRONICKEL-COPPER-CUPRONICKEL MULTILAYER COMPOSITE

Note thickened area of outer layer at the high spots, and especially at the rim where the greatest amount of wear occurs initially.

Wear of the surfaces and the consequent change in the proportions of outside layers and core will affect the electrical resistivity x density product. Abrasion tests of actual coins should be made to verify the fact that the resistivity x density will remain within acceptable limits throughout the life of the coin.

Manufacturing the Strip

Several methods are available for industrial preparation of multilayer composites. Cold bonding, hot bonding, brazing, and explosive bonding are some of the methods that have been successful. The Mints could be adapted to perform the first three methods, though time must be allowed for the development of the necessary skills. The explosive

bonding method could be used to supply composite slabs for rerolling by the Mints in much the same manner as they now process silver-alloy slabs.

Still to be established are the manufacturing tolerances for the composite. Trial production runs by the Mints should be made to reveal any difficulties that might arise in the production of the strip.

Weight

The weight of the new dime made from either a cupronickel on copper combination or the 40 per cent silver alloy on copper composite would be between 2.16 and 2.23 grams, compared with 2.50 grams for the weight of the present dime. In order to behave properly in all coin-operated devices, the weight of the dime should be a minimum of 2.2 grams throughout its lifetime. Apparently, therefore, some design changes, such as a thickened border, would be necessary in the dime in order to increase its total weight. A thickened edge would also be beneficial in that the amount of wear (in terms of thickness reduction) would be reduced.

Scrap Recovery

Blanking scrap in the Mints and miscellaneous scrap in preparing the multilayer composite might amount to as much as 35 per cent by weight. The over-all composition of the scrap from the silver alloy on copper composite would be 16.52 per cent silver, 78.55 per cent copper, 2.65 per cent zinc, and 2.07 per cent nickel. The outer layers alone would contain 20.65 per cent copper. Calculations based on the copper distribution in the outer layer and in the core show that up to 26 per cent scrap could be remelted to make all the alloy needed for the outside layers. Any excess scrap would have to be refined, rather than remelted.

While this will result in a considerable amount of additional handling, the increased cost would not be great. Recovery of the metal, valued at slightly more than $3 per pound, should not be difficult for this composition. The costs of processing to sheet and the costs of making the composite would be lost, irrespective of whether the scrap could be remelted or not.

The scrap problem with the cupronickel-copper combination is minimal. If the scrap did not exceed 33.3 per cent of the total amount of composite processed, all the scrap could be used to prepare the material for the outer layers of the composite. The excess could also be used for making the cupronickel alloy for the five-cent coin.

The Outer Edge

The appearance of coins made from a copper-cored composite would be noticeably different from the present coinage. As discussed earlier, the distinctive red-appearing edge would be an asset in that counterfeit and illegal duplicates could be easily recognized. The anti-counterfeiting could be further enhanced, according to a suggestion made by a Mint source, by engraving the copper edge with a special design during the upsetting operation.

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On the other hand, departure from the present appearance might be considered a severe disadvantage. Moreover, exposing the functional features of the coin might invite slugging by suggesting inexpensive materials capable of acceptance in present-day coin selectors.

Both the advantages and disadvantages must be considered. While the advantages may balance the disadvantages, it might be preferable to avoid the problem altogether by devising a means of obtaining an all white edge. Accordingly, the Mint should give consideration to the possibility of redesigning its upsetting tools to shape the outer edge of the blank in such a way that the coining operation covers the core material with the outside layers. Figure 4 shows the suggested procedure. Other ways are no doubt possible and should be studied.

POSSIBLE ECONOMIC CONSEQUENCES OF A CHANGE IN COINAGE MATERIAL

Although beyond the original scope of this study, certain approaches to lessening the impact of a coinage change on the Public, and its consequent effect on the economy should be considered.

The principal problem to be faced is the possibility that the present coinage might be withdrawn by the public. In order to eliminate the economic incentive for the public's withdrawing the present silver coins, the Treasury stocks can be used to maintain the price of silver below the point at which withdrawal and meltdown would be economic. At a minimum this will be necessary throughout the period of transition while large amounts of the new coins are being placed in circulation.

Withdrawal of the present silver coinage for sentimental reasons is much more difficult either to predict or to control. However, if a policy were to be established for <u>not</u> calling in the present coinage, a favorable psychological climate could be created. Publicity releases could give assurances that

(1) The present coinage will not be withdrawn by the Government.

(2) The silver price will not be permitted to rise for a considerable time.

(3) A change of the coinage alloy will in no way affect the purchasing power of the coins.

(4) The silver supply and demand situation has been reconciled and no crisis will occur.

Conversely, legislation prohibiting melt down of silver coins and prohibiting export of silver would create a climate suggesting that a problem exists. The consequences of such a climate would be to encourage hoarding of coins for both sentimental and speculative reasons.

Since the above suggestions are outside the scope of the present study, they are not included in the Recommendations.

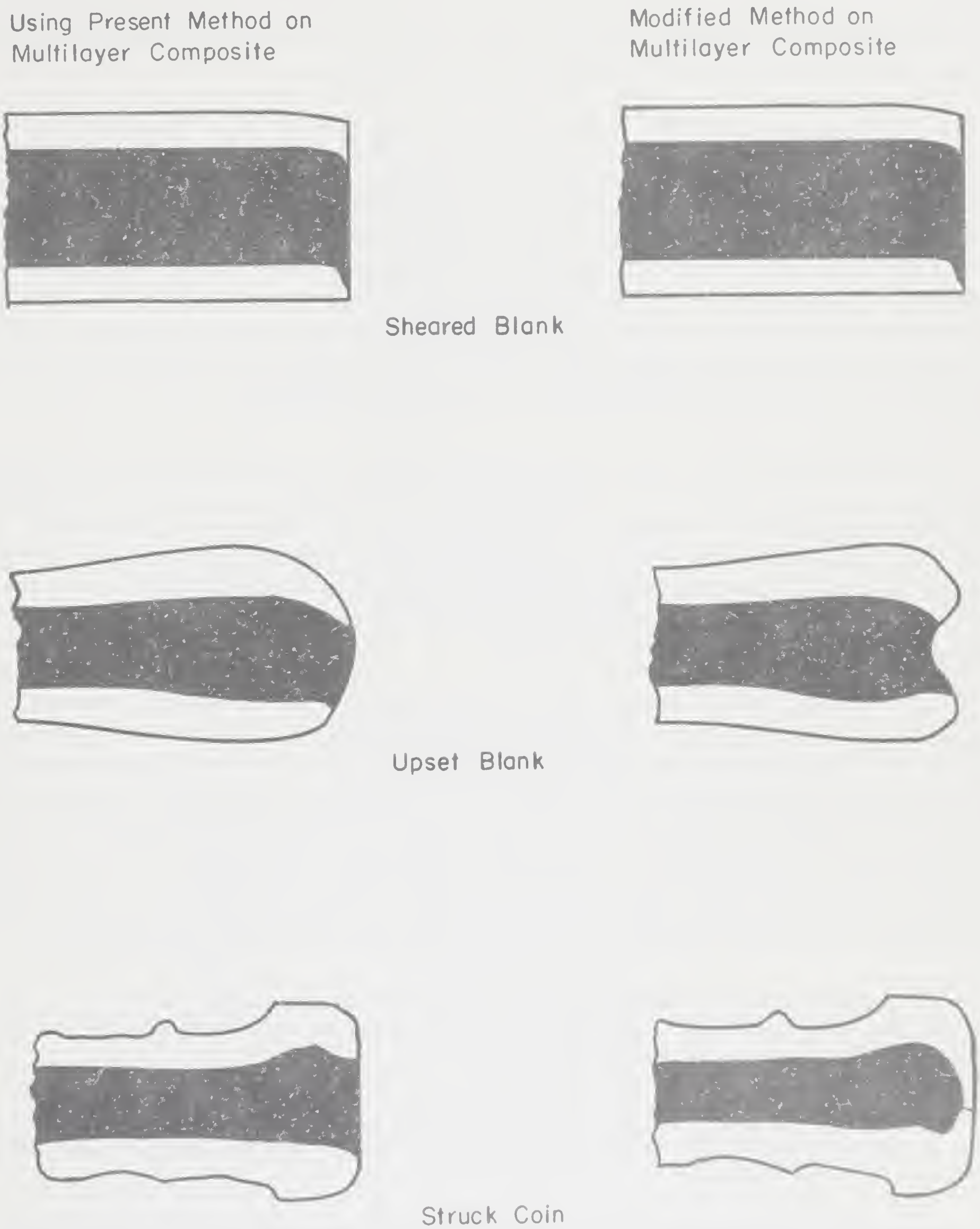

FIGURE 4. A SUGGESTED MEANS FOR OBTAINING A WHITE EDGE ON A MULTILAYER COMPOSITE COIN CONTAINING A COPPER CORE

CONCLUSIONS AND RECOMMENDATIONS

Taking into account the various criteria for U. S. coinage materials, Battelle presents the following conclusions and recommendations:

1. A multilayer composite consisting of cupronickel (or, conceivably, nickel silver) clad on a copper core used in all of the subsidiary denominations seems to offer the best over-all solution to a complicated problem. This recommendation can only be a conditional one since the Mint must determine that it will be able to obtain adequate amounts of the composite material from commercial suppliers until it develops its own capabilities in this area. Experimental strikes have produced very attractive coins but the Mint must also determine that there are no unresolved problems that would stand in the way of a large scale production effort on the new coins. Therefore, it is recommended that the Mint undertake whatever steps are required in order to establish beyond doubt the availability of the needed multilayer material and the feasibility of making large amounts of coins of satisfactory quality.

2. In the event that some unforeseen problem should disqualify the cupronickel composite material for use by the Mint, it is recommended that the new coins be made from the homogeneous 75 copper - 25 nickel alloy. A slightly less preferable, but still acceptable, alloy would be the 65 copper-18 nickel-17 zinc nickel silver. In any event, the Mint may wish to consider the eventual use of a homogeneous base alloy after a multilayer composite has provided the time needed for gradual adaptation of vending machines to accept both old and new coins.

3. The retention of some silver in the coinage is desirable on the basis of tradition and prestige if this can be accomplished without compromising the achievement of other more important objectives. Analysis of the silver supply-demand situation suggested that no more than 15 per cent of projected subsidiary coinage requirements could safely be in the form of silver. Furthermore, the possibility is recognized that even at this reduced rate of use, silver might have to be removed from our coinage altogether within 10 to 15 years. However, within these limitations, it may be adjudged desirable to continue some silver in the coinage. In such an event, and ignoring the special case of the silver dollar, there would appear to be two general options:

(a) Use the 15 per cent, or so, of silver in the 50-cent piece. In the interest of a minimum change in appearance, a multilayer could be used with 80 per cent silver clad on a lower content silver-copper core.

(b) Spread the 15 per cent, or so, of silver throughout the subsidiary denominations. In such a case, the 400 fineness Swedish alloy could be clad on a very low content silver-copper core.

Legislation establishing either of these materials could include specifications for a material containing no silver. A cupronickel (75-25)-copper (silver bearing) combination made to the same dimensions as specified for the silver alloy-copper core composite shown above could be authorized as a replacement for the silver alloy composite when the silver stocks dropped to any level decided upon, or at any given date. It is suggested that the date for the second changeover be set at July 1, 1975, and that earlier changeover be permitted if the Treasury's silver stock should drop below

200,000,000 ounces before that date because of unexpected demands on the stock. The amount would be arbitrary and could be decided at a later date. It would necessarily be dependent on the defense needs, outstanding silver certificates, and world silver situation.

APPENDIX A

SUPPLY-AND-DEMAND OUTLOOK FOR SELECTED METALS CONSIDERED AS ALTERNATIVES TO SILVER IN UNITED STATES COINAGE

CONTENTS

APPENDIX A

SUPPLY-AND-DEMAND OUTLOOK FOR SELECTED METALS CONSIDERED ALTERNATIVES TO SILVER IN UNITED STATES COINAGE

Introduction

This section discusses the adequacy through the year 2000 of 11 metals considered as possible replacements for present metals in United States coinage. These metals are:

Aluminum	Molybdenum
Chromium	Nickel
Columbium	Titanium
Copper	Tungsten
Manganese	Zinc
Zirconium	

The supply relationships presented in this analysis are based for the most part upon data published by the Bureau of Mines. Of particular value is the Bureau of Mines publication Bulletin 585*.

These data on availability are summarized for the above metals in Table A-1. The data on silver availability are also shown for comparison. In most instances, availability represents reserves of metals in the ground, reserves being metal content of measured, indicated, or reasonably inferred ores considered extractable in terms of present economies. In contrast, resources are considered as the metal content of deposits not utilized at present prices but of sufficient grade to represent potential sources of the metal in the event of emergency-induced shortage or at higher prices induced through other scarcity.

The indicated demand upon available reserves of these 11 metals through 1980 and through the end of the year 2000 are also summarized in Table A-1. These data are based partly upon projections by Landsberg, et al.**, in Resources in America's Future. Subsequent sections discuss the rationale of the supply outlook for each metal summarized in Table A-1 and the degree of certainty reflected in these projections of demand.

For the United States, scarcity of a metal resource might result either through loss of foreign sources of raw-material supply upon which this country is dependent, or through the world industrial demand for the commodity exceeding production capacity and/or resource limits. In either case, scarcity is accompanied by rising price levels which for a coinage metal could result in the melting or hoarding of currency for its metal content. This is the situation this country now faces in the use of silver as a coinage metal.

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*Mineral Facts and Problems, Bulletin 585, Bureau of Mines, 1960 Edition, U. S. Govt. Printing Office, Washington, D. C.

**Landsberg, H. H., Fischman, L. L., and Fisher, J. L., Resources in America's Future, John Hopkins Press, Baltimore (1963).

To avoid similar scarcity for an alternative coinage metal at some future time, selection of the metal must rest upon definite economic criteria. First, Free World and domestic reserves and potential resources of the metal should be sufficient to meet projected Free World demands, preferably through the year 2000, whether or not the United States is sufficiently endowed to meet its own requirements. Second, access either to reserves or potential resources must be assured under prolonged emergency conditions. Further, anticipated demands for the metal, for coinage purposes, should not induce scarcity, per se. Also, industrial users of the metal should have the economic and technological alternative of turning to more plentiful substitutes in the event of scarcity. Finally, production capability must be adequate to meet peak demands for the metal for coinage and industrial uses.

Projections of total Free World demand for these metals through the close of the century are subject to varying degrees of uncertainty. For this reason, three estimates of cumulative demand are projected: a conservative estimate, a medium most probable outcome, and a high estimate. These are then compared with Bureau of Mines estimates of availability, tempered by judgments regarding future rates of discovery and the economic potential for utilization of low-grade resources.

Aluminum

The outlook for aluminum metal, both from the viewpoint of demand and supply, appears bright. As the latest metal to find large-scale use in industry, rapid increases in demand have been accompanied by successful exploration efforts for bauxite, the preferred ore of aluminum. The expectation for continued discovery of high-grade ores also appears excellent.

Reserves of aluminum of 800 million tons, given in Table A-1, represent a yield of 1 short ton of aluminum from 4 long tons of bauxite. This conversion factor is applied to the U. S. Bureau of Mines' estimate of bauxite reserves, dated December, 1958.

Medium projections of demand for aluminum metal in the United States through the year 2000 of 255 million tons, shown in Table A-1, are based upon a projected rate of increased usage of 5.2 per cent per annum through 1980 and a rate of 4.3 per cent in the period 1980-2000.

Assuming that changes in demand for aluminum in other non-Communist countries match those of the United States, cumulative Free World consumption of aluminum metal would equal 500 million tons by the year 2000. This medium projection would utilize only two-thirds of the indicated Free World reserves of the metal. On the other hand, if consumption of aluminum in other non-Communist countries eventually exceeds that of the United States, as might be expected because of the present lower per-capita consumption in other countries, then total Free World cumulative consumption would equal or exceed present reserve estimates. This outcome is unlikely, however, because exploration could at least double present reserves of aluminum ore in the next four decades.

In the United States, domestic production supplied only 15 per cent of domestic requirements for bauxite in 1963. Most of the aluminum metal produced for consumption

in the United States is derived from Jamaica and from Surinam ore. As shown in Table A-1, these reserves of aluminum metal contained in bauxite, plus our own limit reserves, are adequate for our needs at least through 1980. Future discoveries to supplement these reserves are most likely to be made in Australia and in Africa. It is only in the relatively well-mapped nontropical areas, such as the United States, that large discoveries of aluminum ore are unlikely.

Economic scarcity cannot be considered a handicap in the consideration of aluminum as candidate metal for U. S. coinage. Compared with total consumption, coinage requirements of even 5000 tons would have negligible effect upon supply-demand relationships. The excess Government metal stockpile is also more than adequate for short-run emergency needs. In the event of a prolonged emergency, domestic low-grade resources could supply this country's requirements for the metal, with little likelihood that the metal value of the coinage would approach its monetary value.

Chromium

World production of chromium ore has doubled on the average of every 10 years in recent decades as a result of fast-growing metallurgical refractory uses. However, nothing in the foreseeable future is likely to change this country's total reliance upon overseas sources for its needs.

Available reserves of chromium contained in chromite ores in the United States, shown in Table A-1, are in the order of 2.7 million tons. These reserves are low in Cr_2O_3 content, are difficult and costly to concentrate, and are therefore undesirable for metallurgical purposes. This also applies to the other limited reserves in the Western Hemisphere.

Projection of demand for chromium in the United States (shown in Table A-1) are tied to projections of steel demand, especially the specialty steels. As shown, the medium cumulative demand in all uses is estimated at 30 million tons of chromium by the year 2000. Added to this is an estimated 110 million tons of other Free World consumption, which results in an average total Free World cumulative demand of about 140 million tons of chromium in the 40-year period.

Because of its dependence upon foreign sources for chromium ores, the United States would be faced with serious transportation problems during wartime. Emergency supplies of chromium raw materials for coinage purposes could be guaranteed therefore only through stockpiling.

In potential coinage alloys, chromium receives attention as an ingredient of both stainless steels and nickel-chromium alloys. In either case, it would not make up more than 20 per cent of the alloy. Hence, stockpiling to permit uninterrupted use during emergencies would be within the range of feasibility. However, emergency conditions, if prolonged, could place critical uses of the metal in competition for such a stockpile.

Columbium

The first commercial use for columbium, developed in the 1930's was as the ferroalloy used in making alloying additions to steel. Since then columbium has been used in the metal form in nuclear reactors. It also shows promise for use in nonferrous high-temperature alloys for aircraft and missiles.

For many years, essentially all the columbium used in the United States was derived from African concentrates of the mineral columbite. During the Korean War, however, in response to a subsidy program, vast deposits of the columbium mineral, pyrochlore, were discovered. These are located mainly in Brazil, Africa, and Canada.

In 1958 the known Free World resources of columbium metal were estimated by the Bureau of Mines to be about 10 million tons*. These resources were predominantly located in South America (7.9 million tons), most of which was in a single deposit in Brazil. North America accounted for 1 million tons of columbium, of which 250,000 tons was in the United States and the rest in Canada.

The largest use of columbium has been in ferrocolumbium, which is used as an addition to stainless steel. No large production-scale uses have yet been established for columbium metal, either in high-temperature alloys or nuclear applications.

There was no domestic mine production of columbium concentrate in 1962, although 64 tons of columbium metal were produced from imports and stocks. In terms of metal content, 1,895 tons of columbium were consumed in the United States in 1962. Of this, 85 per cent was as ferrocolumbium.

Industry representatives report that present mine and mill ore-concentrate capacity is rated at about 700 tons of contained columbium metal in Canada and 2,500 tons in South America. It is estimated that within 2 years Free World mining capacity could be expanded to produce additional ore containing 5,000 tons of the metal annually to meet demands for coinage if this metal were chosen for such service. Interim demand could be met from Government stockpiles of raw materials, which contain an estimated 5,000 tons of columbium metal.

Present extraction capacity in the U. S. is thought to be about 1,400 tons annually, while capacity for reduction of the oxide is in excess of 1,000 tons annually. The consensus of industry is that capacity for the reduction of 5,000 tons of columbium per year could be realized within 1-1/2 years. Melting and forging capacity are considered adequate for any projected demands for the metal. However, annealing of columbium requires special high-temperature vacuum furnaces. Presently, the total U. S. capacity for this type of annealing is only 500-750 tons per year. Sufficient annealing capacity could be made available in 1-1/2 years.

Columbium is quoted at about $50 a pound, although going market prices are considerably below this. One producer suggests $18-$20 per pound as the present selling price for quantity orders.

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* 15 million tons of contained Cb_2O_5 (containing 70 per cent columbium) in total Free World resources.

It is expected that the price of columbium will decrease in the future as volume of production increases. Industry representatives contacted believe that, with a market for 5,000 tons or more of the metal, the price of sheet or strip product would ultimately be in the range of $12-$13 per pound. The value of revert scrap, it is estimated, would probably range from $1 to $3 per pound.

Future demand for columbium depends partly upon the outcome of technological developments that will affect its cost of production and partly upon research and development which might extend its application. Therefore, any projection of future demand at this stage would be subject to a high degree of uncertainty. All that can be said is that considerably more columbium is available in known resources than will be required in the foreseeable future.

Foreign supplies of columbium are vulnerable to political and emergency uncertainty. In view of this risk, one must give special emphasis to the North American resources. Probably these would be adequate to provide the needs for coinage and accelerated industrial uses if other supplies were cut off.

Copper

The United States has long been the largest copper-producing and consuming country in the World. However, since World War II this production has been insufficient to meet the accelerated demands, and imports have been required to meet about 25 per cent of this country's needs.

Official estimates based upon Bureau of Mines statistics published in the 1960 edition of Mineral Facts and Problems place United States reserves of copper at 32.5 million tons. Landsberg, et al., suggest that U. S. reserves of copper, taking into consideration additional ores not included in the Bureau of Mines estimate, may be on the order of 40 to 50 million tons. A further reliable reserve is to be found in the estimated 30 million tons of recoverable copper-in-use in the United States.

Other reserves of new copper include about 66 million tons in the Western Hemisphere, with Chile along accounting for 46 million tons. Total Free World reserves inclusive of the United States are estimated to be 153 million tons of copper. An additional 100 million tons of inferred ore is also thought to exist in Chile and in Africa.

Medium projections of cumulative copper consumption in the U. S. during the 1960-1980 period are estimated by Landsberg to be 42 million tons, and 112 million tons for the 1960-2000 period. To this should be added foreign demand in non-Communist countries of between 350 and 550 million tons, for an average Free World cumulative demand of about 560 million tons in the next four decades.

Although known and inferred copper reserves do not balance this projected demand for Free World copper, there are compensating factors. Indications are that low-grade foreign ores not included in the estimates are of a grade higher than that mined in the United States today. Additionally, new discoveries, or the substitution of aluminum for copper, could make up the deficit. The figures do indicate, however, that the United States may rely increasingly upon foreign sources to meet projected domestic demands.

As an alloy substitute for silver in United States coinage, it seems unlikely that the metal value of copper would ever exceed the monetary value, at least in coins of larger denomination. (Table A-2, at the end of this Appendix, shows the price of copper relative to silver.) Then, too, the amount of copper required for coinage is quite insignificant in relation to overall copper demand. However, war-induced scarcity would possibly require that an adequate stockpile of copper be maintained for coinage purposes.

Manganese

Although manganese is indispensable as a ferroalloy addition in steel-making, commercial reserves of the ore in the U. S. are limited. Because of this, the United States is faced with the problem of finding an economical means of utilizing large low-grade resources for emergency purposes.

In the 1960 edition of Mineral Facts and Problems, the Bureau of Mines estimates that world reserves of manganese ore are in the order of 1 billion tons. Two-thirds of this is in the Communist countries with the remainder in India, Brazil, Union of South Africa, and Gabon.

A summary of information regarding contained manganese in these Free World deposits is shown in Table A-1. As shown, the Free World manganese reserve is on the order of 185 million tons, with less than 1 million tons available domestically. The manganese content of low-grade manganese resources available in this country, however, is estimated to be on the order of 77 million tons.

The projections of cumulative demand for manganese shown in Table A-1 are correlated with projections of steel production. For the United States, estimated cumulative demand for contained manganese in manganese ores through the year 2000 is 73 million tons. Assuming that steel production increases at a rate of 5 per cent annually in other Free World countries, an additional 225 million tons of manganese will be required in the four-decade period. The resulting deficit between world demand and supply could likely be accommodated by slightly lower grade resources and improved beneficiation techniques. Ocean-floor deposits and new discovery possibilities also offer promise of relieving the long-term supply situation.

From the foregoing it is evident that high-grade manganese ores for production of metal for coinage are strategically in short supply in the United States. Stockpiling of high-grade ores or electrolytically refined metal might therefore be required to meet emergency-induced shortages of the metal. However, low-grade resources could likely alleviate any prolonged shortage of the metal for defense as well as coinage needs.

Molybdenum

In recent years suppliers have been hard pressed to meet rising demand for molybdenum, either as a metal or as an additive in steelmaking. However, large-scale exploration has greatly improved the supply outlook for the metal lately.

Most of the world's supply of molybdenum is restricted to the Western Hemisphere. This combined reserve is considered to be in excess of 2 million tons, of which over half is in the single Climax Molybdenum deposit in Colorado. Most of the remaining reserve is recovered as a by-product of copper ores mined in the Western states and in Chile.

Projections of demand for molybdenum, shown in Table A-1, are related to rising steel production and possible space-age needs. Allowing for both domestic consumption and exports upon which the rest of the Free World is dependent, medium cumulative requirements might exceed 3 million tons of molybdenum by the year 2000.

These projections suggest that, even at the medium level of demand, a supply problem could develop in the latter part of the century. Adequacy, therefore, will depend upon recent and future discoveries. Greater recovery of by-product molybdenite from copper ores might also alleviate the long-term supply situation.

Molybdenum ranks high on the list of candidate metals for coinage in terms of economic potential. Because the Western Hemisphere is well endowed with the metal, sources of the metal would be available during emergency periods. However, with one-third of future supply expected to be obtained as a by-product of copper mining, major fluctuations in copper production could create supply problems. Also, coinage would constitute one of the single largest markets for a metal such as molybdenum. It is likely that production could not easily accommodate this added demand, especially during peak periods of economic activity.

Nickel

Despite shortages induced by emergencies in two recent wars, the outlook for enough nickel to meet requirements seems satisfactory. With the exception of Cuba, the world's largest known reserves of nickel are located in Canada in the provinces of Ontario and Manitoba. Of the 6 million tons of Canadian nickel reserves shown in Table A-1, the International Nickel Company controls 4 million tons. Other important Free World reserves are in New Caledonia, the Philippines, and in Puerto Rico.

Reserves in the United States, located in Oregon and Alaska, are estimated to contain about 500,000 tons of nickel. These deposits, however, have supplied only about 15 per cent of United States requirements in recent years, almost entirely for defense stockpiles. It is considered unlikely that economic incentives would add measurably to these United States reserves.

United States nickel consumption, which was 124 thousand tons in 1963, is projected to increase fivefold by the year 2000. This constitutes a cumulative demand of nearly 12 million tons of nickel in the period. Assuming a slightly faster growth for steel production in other countries, Landsberg projects other Free World consumption to accumulate to about 25 million tons.

These requirements are three times the present known reserves listed in Table A-1 but are about equal to resources plus reserves. It is likely, therefore, that a transition to lower grade ores in the future will be necessary. Development of the Cuban laterite ores prior to expropriation has demonstrated the feasibility of this.

There is, of course, the expectation of additional discoveries of nickel sulfide ores in Canada of the Sudbury type as well as the extension of reserves of known deposits in Canada. The outlook for nickel sufficiency is therefore at least as good or better than for most of the other candidate coinage metals.

Titanium

The titanium metal-producing industry was initiated in the early 1950's in response to Government stimulation to meet military needs. These followed a period of rapid growth in which world production of titanium sponge metal reached 17,000 tons by 1957. Subsequently, with an abrupt change in defense effort away from use of titanium metal in manned aircraft, production slumped to less than one-fourth of production capacity.

In the 1960's, new uses for titanium in aircraft and missiles began to develop, and applications in new fields were established through research and development. Accordingly, world production of titanium sponge had risen to a level of nearly 10,000 tons in 1963 in response to a market that shows promise of continued growth.

The mineral generally used for making titanium sponge is rutile, although ilmenite and altered ilmenite might be considered suitable under conditions of scarcity. Rutile is the preferred ore for sponge production because of its high titanium content (94 per cent TiO_2), its lack of iron, and the fact that it lends itself to direct chlorination in the process of sponge production.

In contrast to ilmenite, domestic reserves of rutile ore are small (see Table A-1), and the mineral base for future expansion of production is limited at present. The United States is dependent upon Australia to supplement domestic production of rutile.

A new venture for the recovery of rutile is that of Sherbro Minerals Ltd., located in Sierra Leone. Early estimates suggest that these reserves are on the order of 30 million tons of high-grade rutile, a figure which exceeds all other comparable reserves in the world. This deposit alone is capable of supplying the world's demand for titanium metal ores for an indefinite period*.

Titanium metal production capacity in the United States is thought capable of meeting coinage requirements for the metal.

In the event of loss of foreign sources of rutile, domestic suppliers of the metal would be forced to turn to ilmenite or high-titanium-bearing slags as domestic rutile reserves were exhausted. The inconvenience of using these resources might result in increased metal costs. However, domestic resources are adequate for foreseeable needs.

*African News Digest, July, 1964.

Tungsten

Having the highest melting point of all the metals, tungsten is essential in many space-age and industrial applications where extremely high temperatures are encountered. This, together with increasing use as an alloying agent in steel, accounts for much of its demand. Thus, increasing demand for tungsten as a metal and as an alloy is assured. Although domestic reserves of tungsten are adequate for this short-run need, long-term adequacy is in some doubt.

Known resources of tungsten in the United States are estimated by the Bureau of Mines to contain about 71,000 tons of tungsten metal. Except where recovered as a by-product, most of these domestic reserves are submarginal.

Total Free World reserves of tungsten are estimated to contain about 320,000 tons of tungsten metal. Although these reserves are widespread, the United States is probably better endowed than any other Free World country. In comparison, reserves of tungsten in China, North Korea, and the U.S.S.R. may be three to four times as great as the combined Free World reserve.

Projections of cumulative demand for tungsten by Landsberg, et al., shown in Table A-1, are based upon unchanged relative use of tungsten per ton of steel produced and constant use in relation to industrial machinery output. The medium projection of U. S. demand through the year 2000 exceeds Free World reserves by about 35 per cent. Assuming that Free World demand rises at the same rate as that of the United States, cumulative demand for the non-Communist countries, inclusive of the United States, might total 1 million tons, equal to about three times reserves.

This projected scarcity of tungsten may be alleviated somewhat by new discoveries, especially in less-thoroughly-explored areas than the United States. Improvements in technology may also permit exploitation of lower grade deposits, the extension of known reserves, and new efficiencies in the recovery of scrap. However, as Landsberg points out, discoveries of large deposits of tungsten, or substitution of other metals for tungsten, will be necessary by 1980 if cost increases and reduced use of tungsten are to be avoided.

The outlook under emergency conditions is less encouraging. Because it is essential to defense purposes and is in short supply, tungsten has been designated a strategic mineral for stockpiling under Public Laws 520 and 774.

Even under various types of incentives, as with the Government-sponsored purchase program, 1951-1956, 4 years were required before peak production was attained. Also, metals that might substitute for tungsten in an emergency, such as molybdenum, might also be in tight supply. It is apparent, therefore, that in an extended period of emergency, use of the metal for coinage might contribute to a shortage of tungsten for strategic and more critical needs. Small amounts used for alloying might be permissible, however.

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Zinc

Since World War II, the United States has relied upon foreign sources of zinc to supplement domestic production to meet expanding industrial and military demands, a trend that has been accentuated by the decline in domestic mine production of the metal.

Zinc is widespread in occurrence, with important Free World production coming from the United States, Canada, Mexico, Argentina, Peru, Finland, West Germany, Italy, Spain, Sweden, Japan, Morocco, the Congo, Rhodesia, and Australia. Total reserves of measured and indicated ore in these and other Free World countries is 72 million tons. The Bureau of Mines judges that additional reserves of inferred ore would at least double the reserve figure for zinc.

Cumulative projections of demand by Landsberg, shown in Table A-1, indicate that United States requirements for zinc in the four decades, 1960-2000, of 69 million tons alone equals or exceeds total Free World reserves of recoverable zinc in measured, indicated, and inferred ores. When other Free World needs for zinc are taken into account (which are at least 50 million tons in the next 40 years at present levels of consumption), the data suggest that a serious deficiency in zinc will result.

The seriousness of this supply-demand situation is mitigated somewhat by the probability that the inferred reserve estimates are on the low side. Improved recovery techniques might also relieve the supply situation somewhat. Nevertheless, the outlook for sufficiency of zinc to meet world demands through the year 2000 is in doubt.

From the standpoint of self-sufficiency for monetary needs in periods of emergency, it is worth noting that more than one-half the world's reserve of zinc is in the Western Hemisphere. Domestic mine output is also a significant factor in supply, and Canada and Mexico are important sources of imports. Zinc from old and new scrap, which yields about 20 per cent of the zinc supply, is an important secondary source of the metal. It should also be noted that the U. S. Government has eliminated zinc from its stockpile objectives. As a result, the stockpile has an excess of 1.5 million tons in inventory.

These data suggest that adequacy of supply should not be considered as any drawback in the consideration of zinc as a minor alloying element for monetary uses.

Zirconium

The source of this metal is the mineral zircon. Most of the commercial zircon is recovered as a by-product in the separation of ilmenite and rutile from black sands in which zircon is a minor constituent. Over one-half of U. S. reserves are associated with Florida ilmenite reserves and production.

As shown in Table A-1, reserves of zirconium in zircon, both in the United States and in the Free World, are quite large. The Bureau of Mines estimates that at present consumption rates the measured reserves of zirconium alone are sufficient for at least 100 years.

Over one-half of the 50,000 tons of zircon sold each year is used in the original mineral form. The remainder of the zircon is used in manufacturing zirconium metal, alloys, and compounds. Most of the zirconium metal produced is for use in cladding of fuel elements in atomic reactors, although a small quantity finds application in ferrous and nonferrous alloys. In recent years, total demand for the metal has been less than 1,000 tons annually.

Availability of zirconium in reserves in the U. S. is sufficient for conceivable needs should this metal be selected for a coinage material. However, increases in metal-extraction facilities would be needed.

TABLE A-1. REQUIREMENTS AND AVAILABILITY OF SELECTED METALS – 1960 TO 2000

	Ag	Al	Cr	Cb	Cu	Mn	Mo	Ni	Ti	W	Zn	Zr
	1960 Indicated Reserves[a], millions of tons											
Availability												
United States	0.026	13	2.7	0.25	32.5	0.9	1.5	0.5	0.63	0.071	13.5	8.0
Canada	0.023	--	1.0	0.75	7.0	--	0.25	6.0		0.028	16.7	
Other		154	--	--	0.7	--	--	--		--	6.8	
Total North America		167	3.7	1.00	40.2	0.9	1.75	6.5		0.099	37.0	
Other Free World		633	179.0	5.50	112.8	185.0	0.50	4.5	5.5	0.222	35.0	17.0
Total Free World	0.170	800	186.0	6.50	153.0	185.9	2.25	11.0	5.8	0.321	72.0[d]	25.0
Free World-Other Resources[b]	--	1000			100.0	77		25.0	90.0	0.300	47.0	
	Indicated Demand, millions of tons											
Requirements – United States Annual Domestic Consumption												
1960	0.005	2.0	0.36	0.001	1.60	1.05	0.031	0.108	0.005	0.006	1.20	0.001[e]
1980 Medium	0.011	5.6	0.68		2.61	1.75	0.052	0.262	0.025	0.010	1.78	
2000 Medium		14.7	1.30		4.62	2.89	0.151	0.563		0.021	3.24	
Cumulative Demand[f]												
1960-1980 Low	0.240[c]	51	8		31	22	0.46	2.8		0.11	22	
1960-1980 Medium	0.345	73	10		42	28	0.65	3.7	0.23	0.15	28	
High	0.390	113	13		52	35	0.86	4.9		0.21	36	
Low		140	20		60	48	1.40	7.0		0.25	50	
1960-2000 Medium		255	30		112	73	2.56	11.7		0.46	69	
High		480	44		181	107	4.18	19.3		0.80	126	
Total Free World – Medium 1960-2000		500	140		560	225	3.00	37.0		1.00	175	

(a) Reserves – contained metal in measured, indicated, or inferred ores.

(b) Resources – contained metal in deposits not utilized at present prices but which are of sufficient grade to represent potential ores.

(c) Industrial use plus coinage for Total Free World. The low rate is based on complete elimination of silver in U. S. coinage; the medium rate includes continued demand for 90% silver coins at the 1963 level; the high rate includes demand for 90% silver coins at full mint capacity.

(d) Measured and indicated reserves only. Inferred ores are considered equal to these reserves.

(e) Zirconium sponge metal.

(f) Projected levels of demand. Medium is most probable.

TABLE A-2. RECENT MARKET PRICES FOR METALS BASED UPON WHOLESALE QUANTITIES OF MELTING STOCK

Metal	Density, g/cm^3	Wholesale Price, \$ per pound	Density-Adjusted Price[a], \$ per pound
Silver	10.5	\$18.852	\$18.85
Aluminum	2.7	0.245	0.06
Chromium	7.2	1.190	0.81
Columbium	8.6	12-13[b]	9.80 – 10.7(
Copper	8.9	0.340	0.29
Manganese	7.4	0.317	0.23
Molybdenum	10.2	3.650	3.54
Nickel	8.9	0.790	0.67
Titanium	4.5	1.320	0.57
Tungsten	19.3	2.750	5.05
Zinc	7.1	0.150	0.10
Zirconium	6.5	12[c]	7.45

(a) A pound of a metal that is of lower density than the density of silver will make more coins than can be made from a pound of silver. The cost of a given number of coins made from silver or any other metal can be compared if the price per pound is multiplied by the ratio $\frac{\text{density of the metal}}{\text{density of silver}}$. Hence, metal price $\frac{\text{density of the metal}}{10.5\ g/cm^3}$ = density adjusted price.

(b) Eventual price for sheet for the large quantities needed for coinage, according to industry estimates.

(c) Sheet price.

APPENDIX B

SILVER SUPPLY AND DEMAND

CONTENTS

APPENDIX B

SILVER SUPPLY AND DEMAND

Silver has been prized and sought for some 5 or 6 thousand years. During this time, it has been used in the arts and as a medium of exchange. In recent times, the metal has won broad usage in industry, and it appears destined to play an increasingly important role in the space age and in national defense in the years ahead.

Since World War II, world consumption of silver has exceeded production, the deficit having been drawn from stocks. Most recently, the depletion of this stock has been accelerated through rising industrial needs accompanied by burgeoning coinage requirements in the United States. This situation, coupled with inelastic production potential and limited reserves, has precipitated an imbalance in supply which demands corrective action.

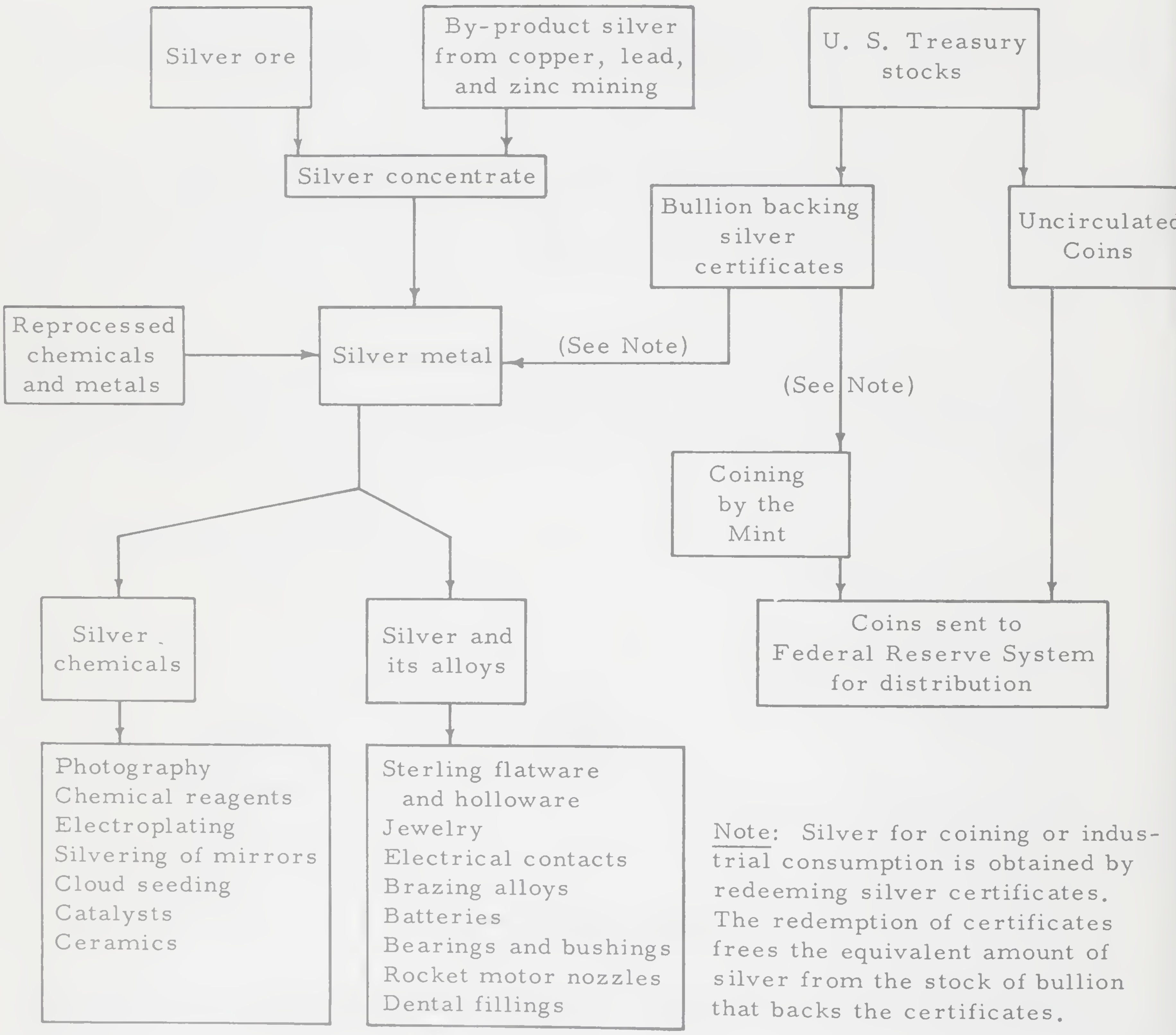
About two-thirds of the silver consumed in the Free World has been for industrial uses (arts and industry). The rest is utilized in coinage. As shown below, consumption by the arts and industry in the 1963 calendar year was nearly balanced by production. However, use of silver in coinage contributed to a Free World deficit of about 210 million ounces:

		Millions of Troy Ounces
Free World production		210.5
Free World consumption		
The arts and industry	247.0	
Coinage	172.2	
Total	419.2	419.2
Deficit (production minus consumption)		(208.7)

Silver Requirements

Silver is one of the noble metals, a designation technically referring only to its superior corrosion resistance. However, silver has other qualities that make it desirable and useful both in industry and in coinage, namely, high malleability and ductility and attractive color and finish. Its properties of high thermal and electrical conductivity account for much of the growing industrial demand for the metal, while the largest industrial demand has long been in photography, where silver compounds are used because of their superior sensitivity to light.

Figure B-1 shows the primary uses of silver and its compounds and the sources from which silver is obtained.



Note: Silver for coining or industrial consumption is obtained by redeeming silver certificates. The redemption of certificates frees the equivalent amount of silver from the stock of bullion that backs the certificates.

FIGURE B-1. TODAY'S FLOW OF SILVER FROM VARIOUS SOURCES TO THE PRINCIPAL CONSUMERS

Use of Silver in Industry and in the Arts

Statistics regarding actual amounts of silver used in the industrial applications shown in Figure B-1 are unavailable. However, reasonable estimates based upon partial data for the United States provide information regarding major uses for the year 1962. These are presented in Table B-1.

TABLE B-1. NET SILVER CONSUMED IN THE ARTS AND INDUSTRY IN THE UNITED STATES IN 1962

Industrial Applications	Millions of Ounces	Per Cent
Photographic processes	33.0	30.0[a]
Solders and brazing alloys	25.0	23.0[a]
Electrical contacts	20.0	18.0[a]
Batteries	5.0	4.5[a]
Silver cyanide for plating	2.0	2.0[b]
Sterlingware and other	25.4	22.5[b]
Total	110.4	100.0

(a) "Silver Price May Rise Still Higher", Chemical and Engineering News, February 4, 1963, p 28.
(b) Estimate.

The Bureau of Mines estimates that industrial consumption of silver in the U. S. in 1963 was 110 million ounces, unchanged from the previous year.* New silver used in photographic processes continued at about the same level as in the previous year, as did silver used in brazing alloys for metal joining. A moderate decline in the use of silver in sterling silverware was registered, however. Increased efforts to develop new substitutes and to use silver more economically in many applications has contributed, at least temporarily, to the leveling off of industrial silver demands in this country.**

Appreciable increases in silver used in the electric and electronic fields were registered in 1963, probably offsetting declines in other fields. Consumption of silver for defense purposes such as rocket nozzles and batteries increased to more than 8.5 million ounces in 1963.

Miscellaneous applications for silver include dental alloys, glass coatings for medical and scientific equipment, water de-salting kits, and silver-plated bearings. Many promising research projects for silver applications have also been announced in 1964.

Figure B-2 and Table B-2 provide information concerning industrial consumption of silver in the United States and in the Free World for the period 1950 through 1964.

*Reprint from Bureau of Mines Minerals Yearbook, 1963, U. S. Government Printing Office, Washington, D. C., "Silver" (J. P. Ryan).

**Handy and Harman report that the total consumption of silver in industry and the arts in the United States and in the other Free World countries in 1964 was up 11 and 15 per cent, respectively, compared with 1963.

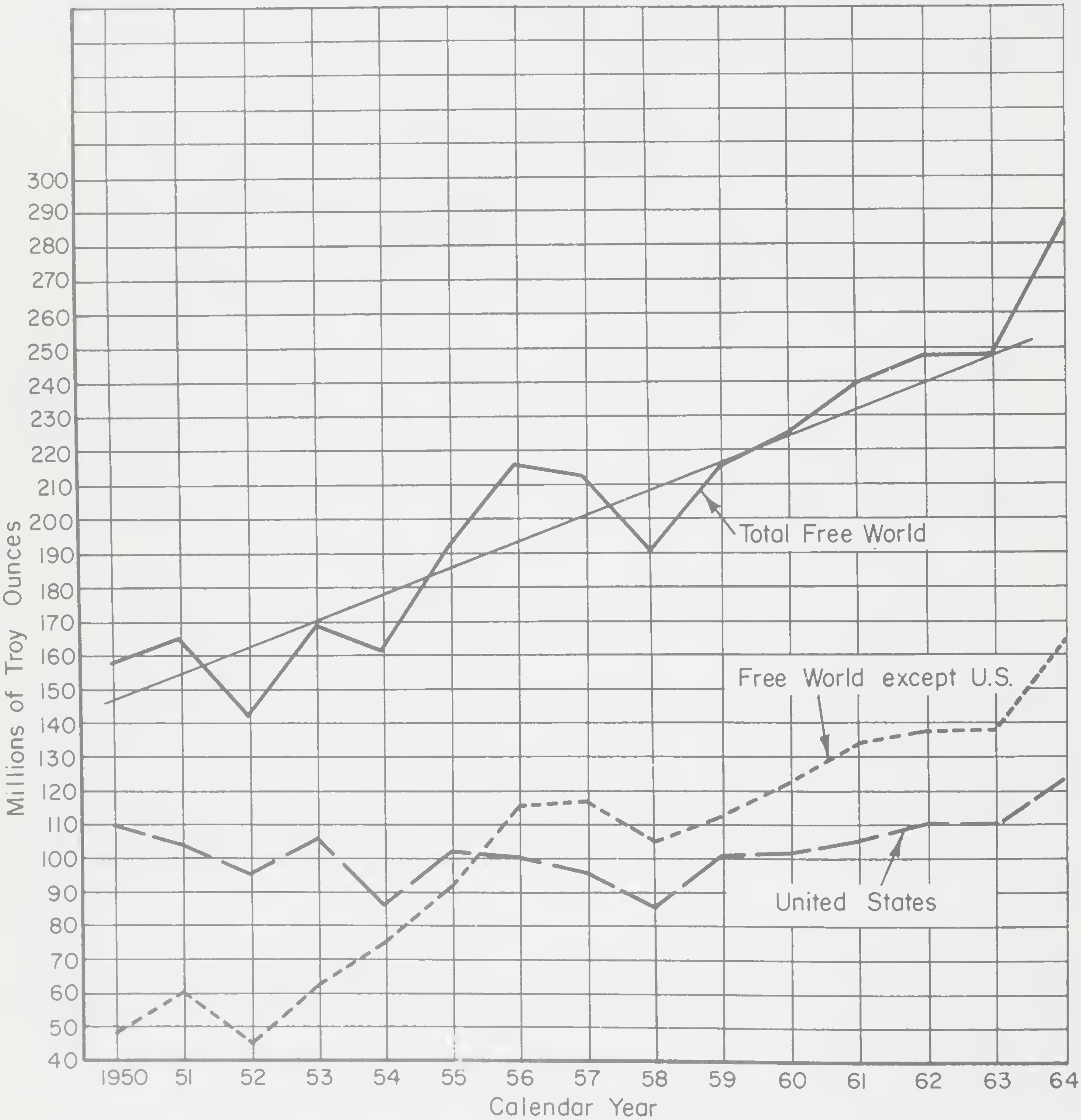


FIGURE B-2. ESTIMATED QUANTITY OF SILVER USED IN INDUSTRY AND THE ARTS IN THE UNITED STATES AND IN THE FREE WORLD DURING THE CALENDAR YEARS 1950-1964

TABLE B-2. ESTIMATED QUANTITY OF SILVER USED IN INDUSTRY AND THE ARTS IN THE UNITED STATES AND IN THE FREE WORLD DURING THE CALENDAR YEARS 1950-1964[(a)]

Calendar Year	Consumption, millions of troy ounces		
	United States	Other Free World	Total Free World
1950	110.0	47.4	157.4
1951	105.0	60.0	165.0
1952	96.5	45.6	142.1
1953	106.0	62.3	168.3
1954	86.0	74.8	160.8
1955	101.4	91.4	192.8
1956	100.0	115.9	215.9
1957	95.4	117.2	212.6
1958	85.5	105.0	190.5
1959	101.0	111.9	214.9
1960	102.0	122.6	224.6
1961	105.5	134.0	239.5
1962	110.4	137.4	247.8
1963	110.0	137.0	247.0
1964	123.0	162.9	285.9

(a) 1950-1963 data are taken from various editions of the Minerals Year Book. 1964 data are reported in The Silver Market in 1964, Handy and Harman, New York.

As shown, total Free World use of silver in industry and in the arts has risen from about 150 million ounces in 1950 to 250 million ounces in 1963, an average rate of about 4.0 per cent per annum compounded. The figure shows that most of this increase was accounted for by countries other than the U. S. In contrast, consumption of industrial silver in this country has been quite level since 1950 at between 90 million and 110 million ounces per year.

Expectations are that industrial demand for silver in the Free World will continue to increase in the future despite the recent price rise in the metal to $1.2929 (an ounce) from $0.925 in 1961. Despite the fact that the use of nonsilver light-sensitive materials in the photographic industry has risen significantly in recent years, the market for silver chemicals in photography is not threatened. Space-age applications and new developments offer significant potential for increased use of silver which should offset declines attributable to substitution or to reduced retail sales.* Therefore, a 2 per cent minimum annual increase in future Free World silver consumption is considered reasonable – perhaps on the low side – for estimation purposes.

Use of Silver for Monetary Purposes

Since passage of the Gold Reserve Act in 1900, silver has played a secondary, though important, role in our monetary system. The metal has been used in subsidiary coins (dimes, quarters, and half-dollars) and in silver dollars, and serves as backing for some 1.2 billion dollars worth of silver certificates in circulation. Altogether, however, silver accounts for less than 3 per cent of the U. S. stock of money.**

Figure B-3 and Table B-3 show the consumption of silver for coinage in the United States and in the Free World for the period 1950 through 1963. The data show that in 1963 the United States accounted for 65 per cent of total Free World coinage as compared with 55 per cent in 1962 and 40 per cent in 1961. As shown, silver used in coinage in the rest of the Free World has declined since 1961, although the trend until 1961 was upward.*** In contrast, silver minted in United States coinage in 1963 increased 34 million ounces from 1962, a gain of 45 per cent. A further gain of 90 million ounces is expected in 1964.

The trend toward demonetization of silver in other Free World countries is continuing.**** For estimation purposes it is assumed that the amount of silver used for coinage in the rest of the Free World will decline to about 30 or 40 million ounces by 1970 from the present level of 60 million ounces.

Projections by the U. S. Treasury indicate that, if the present scarcity of coins persists, the amount of silver required for United States coinage in calendar year 1965 will be about 290 million ounces,***** up from 201 million ounces in 1964. Should

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*Silver nitrate, the base for much of the silver used in industry, offers one measure of demand for silver used in the United States. Based upon the content of silver in this compound (63.5 per cent), this use has shown a steady increase from about 35 million ounces in 1950 to 55 million ounces in 1963, a compound rate of increase of about 4 per cent each year. This growth might be slowed somewhat due to the growing use of color film, which utilizes less silver than black-and-white film and offers higher recovery of silver used.

** "The New Silver Law", Monthly Review, Federal Reserve Bank of Richmond (July, 1963).

***Total use of silver for coinage rose in 1964, primarily because Japan issued a silver Olympic Games commemorative coin.

****Australia and South Africa are planning to abandon silver in 1965.

*****This forecast represents short-run cyclical demand for about 8-9 billion coins. The silver consumption is based on the 90 silver-10 copper alloy. In the long run, the Arthur D. Little forecast of 4-5 billion coins annually is considered more appropriate.

coinage demand continue to increase in this country, the United States Mints, working at capacity, might continue production at the 1965 level into 1967, when production could be increased further as the new Philadelphia Mint begins operation. The rate of increase in coinage demand is approximately the same for both silver-containing and non-silver-containing coins (see Figure B-4 and Table B-4). This suggests that much of the present demand for silver coins is in response to real economic growth, intensified by above-normal interest by speculators and coin collectors. It is possible, therefore, that short-run coinage demand could follow a cyclical pattern as it has historically. Thus, it is possible that a down-turn in demand for subsidiary coins could develop by mid-1965.

Sources of Silver

Production

World production of silver in 1960 was estimated as 249.5 million troy ounces. Of this, some 39 million ounces was produced in Communist countries. Of the remaining 210 million ounces, which represent Free World production, 53 per cent was mined in North America, 22 per cent in South America, 8 per cent in Europe, 3 per cent in Africa, 9 per cent in Oceania, and about 5 per cent in Asia.

Mexico, which has long been the leading producer of silver, accounted for 42.8 million ounces of silver in 1963. The second largest producer was Peru with 36.4 million ounces. The United States was third with 35.0 million ounces, followed by Canada with 30.7 million ounces of newly mined silver.

The silver mined in the Free World is commonly produced as a by-product or co-product of copper, lead, and zinc. Two-thirds of the domestic silver mined is recovered as a by-product of these ores. Virtually all of the remainder comes from siliceous silver vein deposits, and only 0.1 per cent of all production is from placer mining.

Figure B-5 and Table B-5 show the trend of silver production in the United States and in the Free World since 1950. As shown, production of silver in the United States has declined in the 14-year period at an average annual rate of about 1 per cent. In contrast, total Free World silver production (including the United States) has risen from 170 million ounces in 1950 to 210 million ounces of silver produced in 1963, an average rate of increase of 1.5 per cent each year.

Because most of the silver produced in the Free World is derived from base-metal ores, silver output is relatively inelastic as a function of price. Liberalized exploration subsidies and higher prices have stimulated exploration and marginal mine production of silver or silver-containing base-metal ores. Nevertheless, projections of future silver production must be based largely on expectations of demand for copper, lead, and zinc.

Silver producers estimate that at least 38 million additional ounces of silver will be produced by 1968. For estimation purposes in this report, it is assumed that Free World production of silver will increase 48 million ounces per year by 1968, to

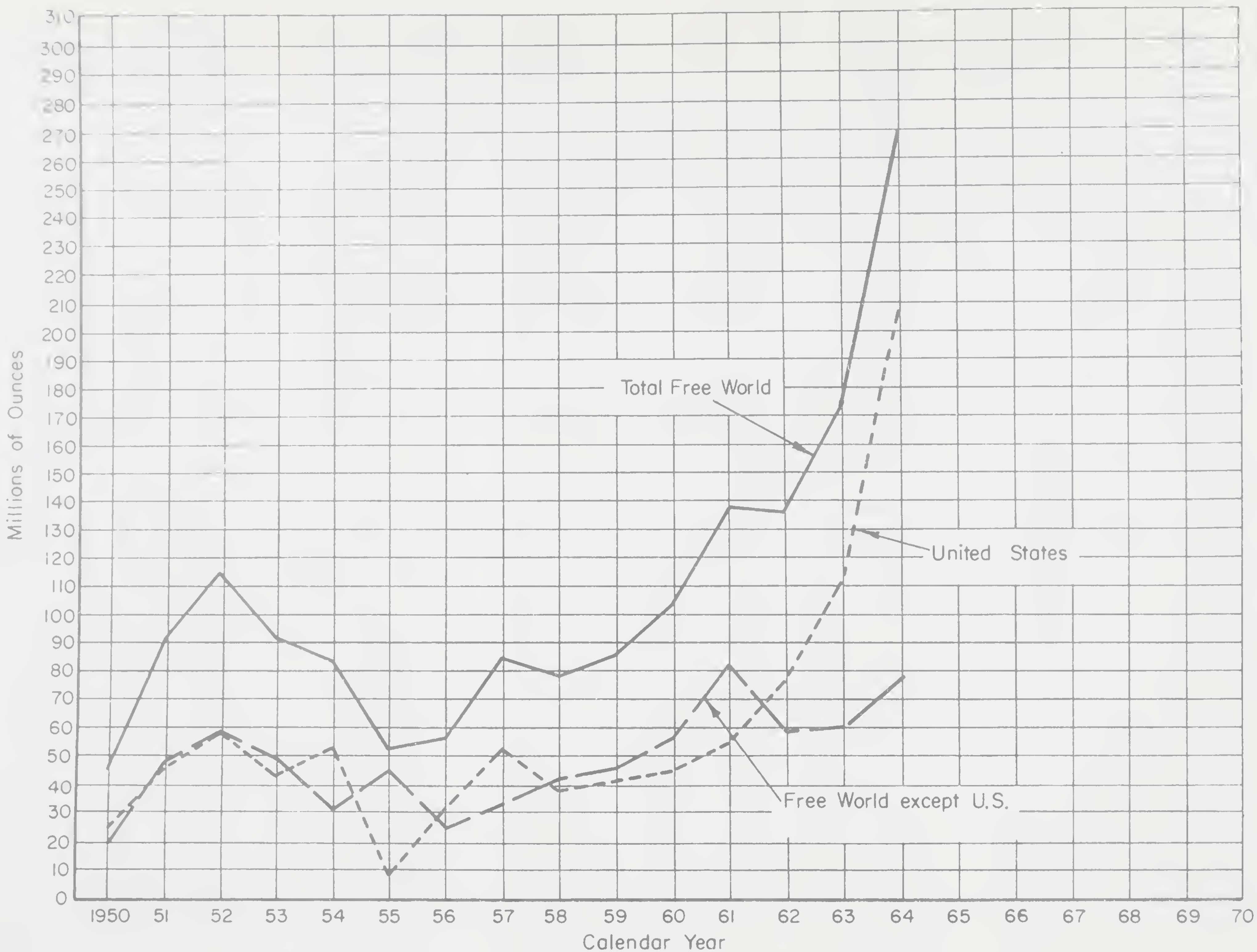

FIGURE B-3. QUANTITY OF SILVER USED IN COINAGE IN THE UNITED STATES AND IN THE FREE WORLD DURING THE CALENDAR YEARS 1950-1964

TABLE B-3. QUANTITY OF SILVER USED IN COINAGE IN THE UNITED STATES AND FREE WORLD COUNTRIES DURING THE CALENDAR YEARS 1950-1964

Year	Consumption, millions of troy ounces		
	United States	Other Free World	Total Free World
1950	24.6	19.5	44.1
1951	44.4	46.1	90.5
1952	57.3	57.0	114.3
1953	42.8	47.9	90.7
1954	53.2	30.2	83.4
1955	8.2	44.4	52.6
1956	31.4	25.3	56.7
1957	52.1	32.3	84.3
1958	38.1	41.4	79.5
1959	41.4	45.0	86.4
1960	46.0	57.9	103.9
1961	55.9	81.2	137.1
1962	77.4	59.0	136.4
1963	111.5	60.7	172.2
1964	203	67	270

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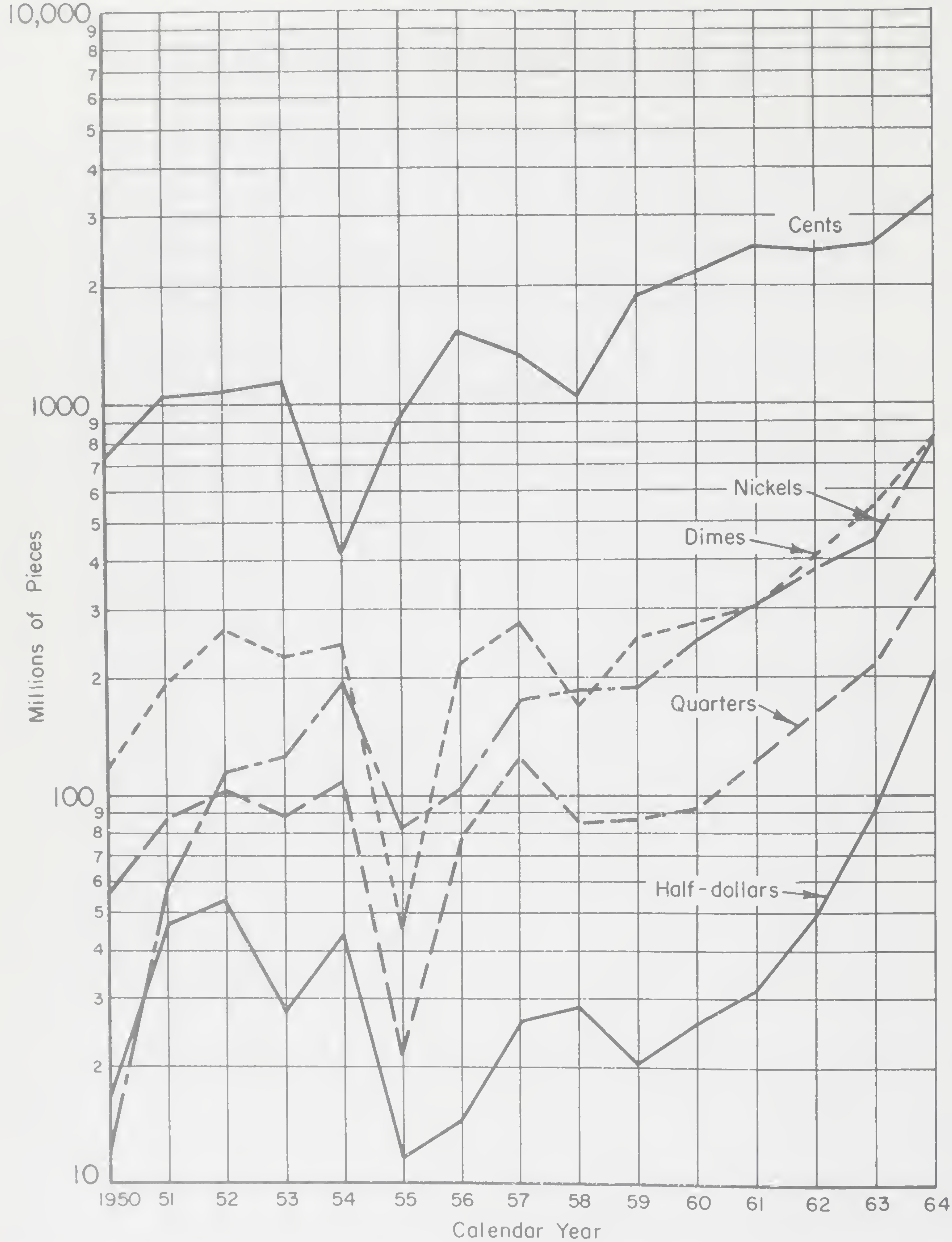

FIGURE B-4. ANNUAL COINAGE OF CENTS, NICKELS, DIMES, QUARTERS, AND HALVES IN THE UNITED STATES FOR THE CALENDAR YEARS 1950-1964

TABLE B-4. ANNUAL COINAGE OF CENTS, NICKELS, DIMES, QUARTERS, AND HALVES IN THE UNITED STATES, FOR THE CALENDAR YEARS 1950-1964

Year	Number of Pieces[a], millions				
	Halves	Quarters	Dimes	Nickels	Cents
1950	16.3	56.3	117.4	12.5	726.1
1951	40.7	87.9	191.1	56.8	1,094.0
1952	54.2	102.4	265.6	115.3	1,070.8
1953	28.0	88.8	229.2	125.9	1,139.2
1954	44.0	108.8	243.5	194.4	419.6
1955	2.9	21.7	45.3	82.7	938.8
1956	4.7	77.1	217.3	103.1	1,519.6
1957	26.3	125.7	274.8	176.5	1,335.1
1958	28.9	85.4	169.4	186.2	1,054.4
1959	20.4	87.6	251.8	189.1	1,890.6
1960	25.9	93.9	272.2	249.7	2,169.0
1961	31.6	123.7	305.9	306.0	2,509.6
1962	48.5	166.9	410.6	380.8	2,402.4
1963	92.3	212.7	548.2	455.7	2,531.2
1964[b]	203.0	383.0	813.0	799.0	3,339.0

(a) The number of pieces for each denomination can be converted to troy ounces of silver by multiplying the dollar value by 0.723.

(b) Estimated December 23, 1964.

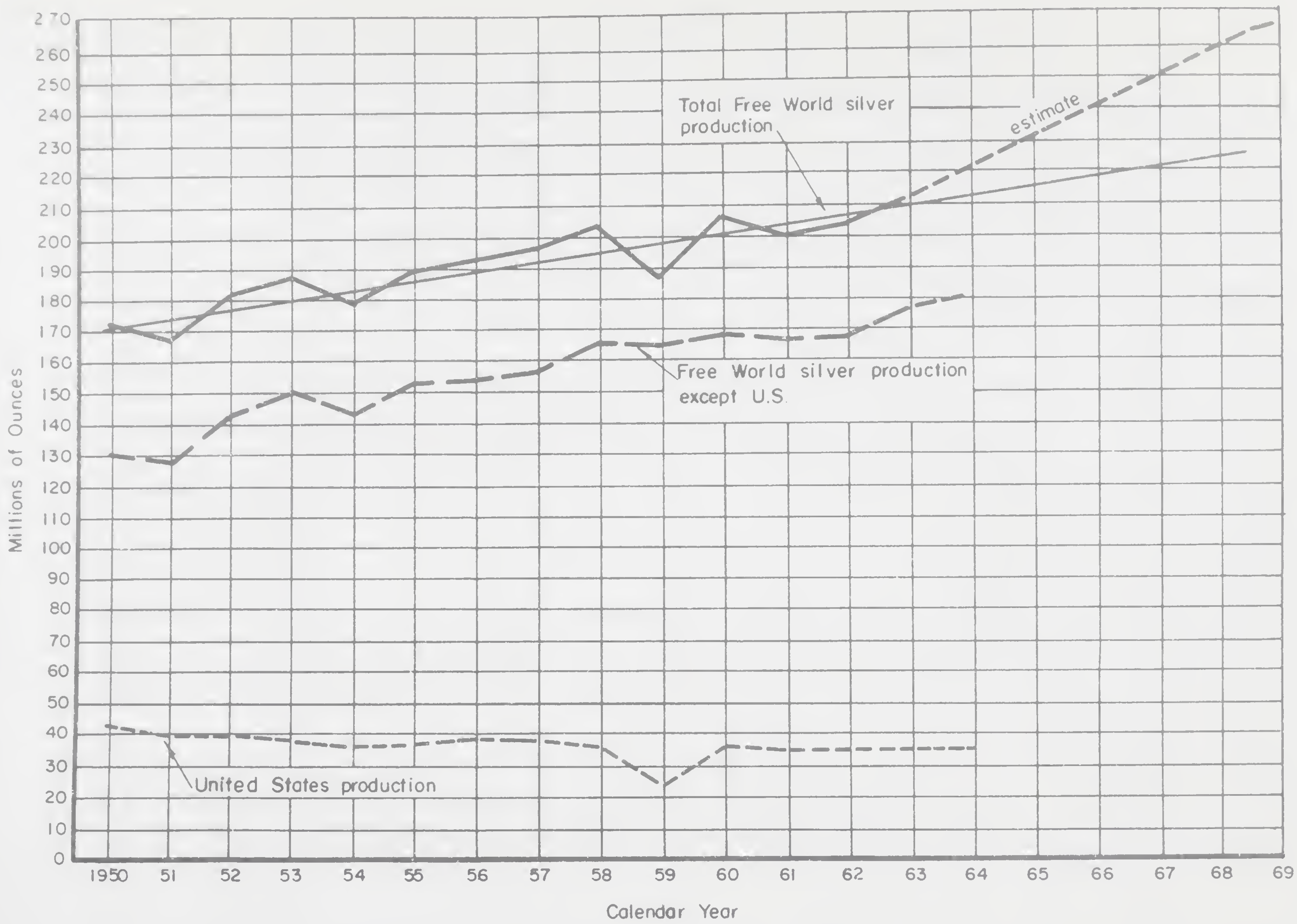

FIGURE B-5. PRIMARY SILVER PRODUCED IN THE UNITED STATES AND IN THE FREE WORLD DURING THE CALENDAR YEARS 1950-1963

TABLE B-5. PRIMARY SILVER PRODUCED IN THE UNITED STATES AND IN THE FREE WORLD DURING THE CALENDAR YEARS 1950-1963

Year	Production, millions of troy ounces	
	U. S. Production	Total Free World
1950	42.3	173.0
1951	39.9	167.7
1952	39.8	182.3
1953	37.7	187.7
1954	35.6	178.0
1955	36.5	189.0
1956	38.7	191.2
1957	38.7	195.4
1958	36.8	202.1
1959	23.0	186.8
1960	36.8	204.5
1961	34.9	199.9
1962	36.3	202.4
1963	35.0	210.0
1964	36.0	215

258 million ounces, from 210 million ounces in 1963. Beyond 1968 it is assumed that production increases will gradually assume past rates of change, with Free World production rising to 286 million ounces of silver by 1975.

Reserves of Silver

The Bureau of Mines estimates that in 1944 total world silver reserves were about 5 billion ounces of recoverable silver (about 170,000 tons). Of this, about 763 million ounces represents reserves of silver in the United States (about 26,000 tons). Since 1944 the depletion of these reserves has been offset, at least in part, by new discoveries of silver-bearing base-metal ores.

If the United States eliminated silver from coinage by the end of 1965, it is estimated that the cumulative demand for silver for all other Free World uses would be about 7.2 billion ounces (240,000 tons) by 1980. This demand is about equal to total world reserves of silver plus nonproductive sources including the U. S. Treasury stock of monetary silver.

Judging from developments since 1944, indications are that discoveries of new silver-bearing base-metal ores will suffice to meet the projected demands for silver

for industry and other Free World coinage. However, should the United States retain a substantial proportion of silver in its coinage it appears that a much higher discovery rate of new silver will be necessary in the next decade than has been the case in the past 20-year period.*

Stocks

In addition to production and unmined reserves, there are a number of world non-productive sources of silver. The sources include stocks held by the U. S. Government and foreign governments, including those of the Communist-bloc countries, silver as coinage in circulation or held in bank inventories, and industrial inventories including raw materials, scrap, and merchandise.

U. S. Monetary Silver. The most important of these stocks is the U. S. Treasury supply of monetary silver. As shown in Table B-6, this stock consists of silver bullion and silver dollars, which serve to back silver certificates in circulation and provide the raw material for manufacturing subsidiary coinage. Silver not needed for backing of silver certificates is termed "free silver" and is made available to the Mint for subsidiary coinage as needed or to private industry. Table B-6 shows that the stock of silver dollars, which was at a level of 242 million ounces in 1950, has been almost entirely depleted. Silver bullion backing silver certificates is estimated to be at a level of 1,190 million ounces at the end of the calendar year 1964. Inventories of subsidiary coin average less than 5 million ounces, reflecting a rapid movement from the Mints to the Federal Reserve Banks.

Table B-6 shows also that the total stock of monetary silver held in the Treasury rose from about 1,980 million ounces in 1950 to a peak of somewhat less than 2,110 million ounces in 1958. In each year since 1958, outflow has exceeded inflow, so that, by the end of the 1964 calendar year, the remaining silver stocks stood at a level of about 1,200 million ounces. Had it not been for Lend-Lease returns, outflow would have exceeded inflow during every year since 1951.

Silver in Circulation. In addition to monetary silver held in the Treasury, the United States monetary silver included 1,700 million ounces of silver in circulation as of December, 1963. An analysis of coin-loss rates, however, suggests that only 65 per cent of silver-containing subsidiary coins minted since 1920 remain in circulation.** Assuming that silver dollars are no longer in circulation, this loss rate suggests that the total amount of silver in coins in circulation at the end of 1963 was 886 million ounces, or approximately one-half that shown in Table B-6.

Deposits and Withdrawals From U. S. Treasury Stocks. Table B-7 itemizes the deposits and withdrawals relative to the Treasury stock during the fiscal years 1950 to

* In the short run, the shortage of silver relates more to production potential than to reserve potential.

** Production Facilities for the United States Mint, Arthur D. Little, Inc., Feb. 11, 1963, in Hearing before a Subcommittee of the Committee on Banking and Currency, United States Senate, Eighty-Eighth Congress, first session on S. 874, U. S. Govt. Printing Office (1963)

TABLE B-6. UNITED STATES MONETARY SILVER HELD IN THE TREASURY FOR CALENDAR YEARS 1950-1964

Millions of Troy Ounces

	Calendar Year														
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964 (est)
In Treasury															
Securing silver certificates															
Silver bullion	1,578.3	1,603.7	1,631.7	1,655.7	1,679.2	1,697.2	1,708.4	1,711.5	1,736.3	1,741.3	1,741.8	1,730.5	1,654.5	1,532.5	1,190
Silver dollars	241.9	232.8	223.8	215.2	207.0	196.1	182.8	169.4	156.8	141.1	124.9	100.7	72.7	22.1	2
Subsidiary coin	2.6	1.2	2.8	4.6	34.5	11.3	2.0	5.9	10.9	2.4	2.0	2.6	2.4	4.5	8
Free silver bullion	159.9	124.5	81.7	49.6	13.6	24.9	87.4	127.4	202.2	175.1	123.5	28.5	37.0	25.2	18
Total	1,982.7	1,962.2	1,940.0	1,925.1	1,934.3	1,929.5	1,980.6	2,014.2	2,106.2	2,059.9	1,992.2	1,862.3	1,766.6	1,584.3	1,218
Net change		20.5	(22.2)	14.9	9.2	(4.8)	51.1	33.6	92.0	(46.3)	(67.7)	(129.9)	(95.6)	(182.3)	(366)
Outside Treasury															
Coinage in circulation															
Silver dollars	139.1	148.0	156.6	164.9	172.5	182.0	195.1	208.3	220.8	236.2	252.3	276.4	303.6	352.9	373
Subsidiary coin	739.4	783.5	837.7	877.5	898.9	928.3	968.0	1,014.6	1,046.2	1,094.6	1,140.0	1,194.0	1,270.3	1,363.4	1,559
Total	878.5	931.5	994.3	1,042.4	1,071.4	1,110.3	1,163.1	1,222.9	1,267.0	1,330.8	1,392.5	1,470.4	1,573.9	1,716.3	1,932
Grand total	2,861.2	2,893.7	2,934.3	2,967.5	3,005.7	3,039.8	3,143.7	3,237.1	3,373.2	3,390.7	3,384.7	3,332.7	3,340.5	3,300.6	3,080

TABLE B-7. DEPOSITS AND WITHDRAWALS FROM MONETARY SILVER HELD IN THE U. S. TREASURY FOR FISCAL YEARS 1950-1964[a]

Millions of Troy Ounces

	Fiscal Year														
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
Deposits (Receipts)															
Retired Subsidiary Coins	1.9	1.6	1.2	0.9	0.9	1.8	1.4	1.3	1.2	1.4	1.0	1.0	1.2	0.9	0.8
Lend-Lease Returns	--	--	--	--	--	11.2	49.4	95.4	119.3	75.0	14.6	3.3	15.6	0.1	--
Silver Bullion Ordinary	0.1	0.1	0.1	0.3	4.4	0.2	1.6	--	0.3	0.5	0.4	0.2	0.6	1.1	0.3
Purchases	41.2	38.1	38.8	35.6	33.7	34.7	15.5	6.6	26.2	20.4	0.7	0.3	0.1	--	--
Uncurrent Silver Dollars	0.2	0.3	0.3	0.3	0.4	0.5	1.4	0.3	0.2	0.2	0.2	0.1	0.3	0.6	0.8
Total	43.4	40.1	40.4	37.0	39.4	48.4	69.3	103.6	147.2	97.6	16.9	5.0	17.8	2.7	1.9
Withdrawals (Issues)															
Coinage	10.8	30.9	56.3	56.1	60.4	16.8	17.2	48.1	49.4	36.5	41.0	42.3	75.2	83.6	144.0
Sold	0.2	1.8	0.1	0.1	0.1	0.2	10.5	7.7	0.1	11.5	30.8	40.7	38.9	2.3	56.4
Total	11.0	32.7	56.4	56.2	60.5	17.0	28.7	55.8	49.5	48.0	71.8	83.0	114.1	85.9	200.4
Net Change	32.4	7.4	(16.0)	(19.2)	(21.1)	31.4	40.6	47.8	97.7	49.5	(54.9)	(78.0)	(96.3)	(83.2)	(198.5)

(a) Silver Transactions of the Bureau of the Mint Fiscal Years 1934 Through 1964, Treasury Department, United States of America, U. S. Government Printing Office, 1964.

1964.* In the past 14 years, the principal sources of deposits have been:

- Worn coins retired from circulation
- Return of Lend-Lease silver
- Purchases of silver on the open market.

The second item, return of Lend-Lease silver, added substantially to the stocks between 1955 and 1962. However, little more silver can be expected from this source. In the 1964 fiscal year, total deposits into the Treasury stocks from all sources equalled only 2 million ounces.

Most of the withdrawals from stock have been for coinage. These withdrawals, as shown in Table B-7, ranged from 11 to 60 million ounces during the period from fiscal 1950 to fiscal 1961 and rose to 75 million ounces in fiscal 1962, 84 million in fiscal 1963, and 144 million in fiscal 1964. Silver-dollar withdrawals rose from 9 million ounces in fiscal 1950 to 50.6 million ounces in fiscal 1963. At present, 3 million ounces remain of the stock of silver dollars. Some silver has been sold to other Government agencies (1 to 6 million ounces per year), some of which is returnable.

Sales of Treasury silver to domestic purchasers or exchanges for silver certificates have also contributed to this deficit. Normally, these withdrawals could be expected to be between 25 and 65 million ounces of silver a year from the Treasury. However, since September, 1964, due to speculation, redemptions have ranged from 21 to 44 million ounces of silver per month, bringing the total for the calendar year 1964 to 141 million ounces. This redemption rate might be slowed in the future if the procedures for redemption were changed.**

Other Free World Stocks. In 1963, important monetary stocks of silver held by Free World countries other than the United States amounted to about 105 million ounces. This was divided between bullion and coin as follows:

	Millions of Ounces of Silver
Silver bullion	78
Coin on hand	27
Total	105[(a)]

(a) Source: U. S. Department of the Treasury (private communication). Total is for 24 countries.

The largest stock of silver was held by Canada, followed by Japan and Switzerland.

Projected Changes in United States Monetary Stock of Silver

Although observers of the silver situation unanimously agree that the end of the U. S. monetary stock of silver is in sight, universal agreement regarding the life

* The fiscal year 1950 began on July 1, 1949, and ended June 30, 1950.

** At present, silver can be redeemed merely by presenting a check to the Treasury. The Federal Reserve Bank then sees that the necessary silver certificates are deposited with the Treasury.

expectancy of this stock is lacking. Before proposing a solution to this situation, therefore, it is important to establish just how adequate this stock is to make up the deficit between projected Free World production and projected Free World requirements of silver. This forecast then serves as a foundation for evaluating alternatives for alleviating the projected scarcity of the metal.

For this forecast, U. S. production, consumption, and stocks of silver cannot be divorced from those of the other Free World countries. Because the factors of supply and demand that affect the life expectancy of these stocks are variable, it is also necessary to prepare a number of forecasts based upon varying assumptions of supply and demand. In this way the risk of an erroneous conclusion in the projected adequacy of silver stocks is minimized. Also, such a forecast directs attention to the controllable factors affecting these stocks, thus suggesting possible solutions to the silver problem.

Assumptions

Table B-8* is a projection of the life expectancy of the U. S. monetary stock of silver based on alternative levels in the silver content of U. S. coins. This forecast combines conditions of high productivity of silver with moderate increases in demand for the metal in industry and in the arts, together with decreasing Free World silver coinage in countries other than the United States.** The uncertainty of projecting future United States coinage rates for this set of possible conditions is reduced by preparing projections for three situations: high, medium, and low rates of coinage demand.

The forecast is based upon the following assumptions:

A. Free World silver production: increase of 48 million ounces per year by 1968 (4.3 per cent annual increase, 1963 to 1968, versus 1.5 per cent annual increase, 1950-1963) and 28 million additional ounces per year of production by 1975 (annual increase of 1.6 per cent from 1968 to 1975) for a total of 76 million ounces increase per year by 1975 (compared with an increase in production of only 40 million ounces per year in 1963 over 1950)

B. Consumption in the arts and industry, total Free World: increasing at an average annual rate of 2 per cent during the period of 1963 through 1975 (compared with an average annual increase of about 4 per cent from 1950 to 1963)

C. Free World coinage other than the United States: decreasing from 60 million ounces in 1963 to a level of 30 million ounces by 1970

D. U. S. coinage demands – possibilities:

Situation I. High Coinage Rate - Demand for coins continues at full Mint capacity of 300 million ounces through 1975

Situation II. Medium Coinage Rate - Continuation of coinage demand at level of 1964 production of 208 million ounces

* Table B-8 is given at the end of this Appendix.

** This represents only one set of possible conditions and is not necessarily the most likely possibility.

Situation III. Low Coinage Rate - Cyclic down-turn in coinage demand beginning in early 1965; demand drops from 208 million ounces in 1964 to 77 million ounces in 1966; demand increases from 1966 through 1975 at the projected rate of 5.1 per cent each year.*

These situations are graphed in Figure B-6. In these projections it is assumed that the total Free World deficit, excluding U. S. coinage, will be drawn from the U. S. Treasury through silver certificate redemptions. This projected world deficit is comparable to average rates of redemption or sales of Treasury silver prior to 1964, and is therefore considered reasonable.

In these projections no attempt is made to include that portion of the world deficit that will be met from other nonproductive sources such as monetary stocks of other Free World governments, private hoards, and retired silver-containing coins. Also, transfer of silver to other Government agencies is excluded from the calculations. Although these deposits and withdrawals may affect year-to-year changes in redemptions of silver certificates, the total amount of silver involved is deemed insufficient to substantially change the outcome of these projections.

No provision is made in these projections for redemption of silver certificates for speculative reasons beyond 1964. Should redemptions continue at the above-average September-December, 1964, rate (due to speculation), the projected life of U. S. Treasury monetary silver would be substantially reduced. It is assumed, however, that the Treasury will continue to make its stocks available at or below $1.38 per ounce in order to remove incentive for melt-down of present subsidiary coinage.

Estimated Life of U. S. Monetary Stock of Silver

The foregoing assumptions now serve as a framework for projecting the changes in the U. S. monetary stock of silver from 1963 through 1975 as a basis for evaluating alternative coinage possibilities. The alternatives considered in Table B-8 and summarized in Table B-9 for high, medium, and low coinage demand are

(1) Continuation of the silver content in coinage at the present level of 90 per cent

(2) Reduction of the silver content of coins to 50 per cent

(3) Reduction of the silver content of coins to 30 per cent

(4) Reduction of the silver content of coins to 15 per cent

(5) Complete elimination of silver in U. S. coinage.

Alternatives 2, 3, 4, and 5 assume no change in the present coinage system prior to December 31, 1965.** Also, no provision is made for the minting of silver dollars in any of the calculations.

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*A. D. Little projected long-run trend of demand for silver-containing subsidiary coins.

**If a change could be made by June 31, 1965, the Treasury stocks would be extended by about 3 years if silver were entirely eliminated from coinage, under the assumptions listed above.

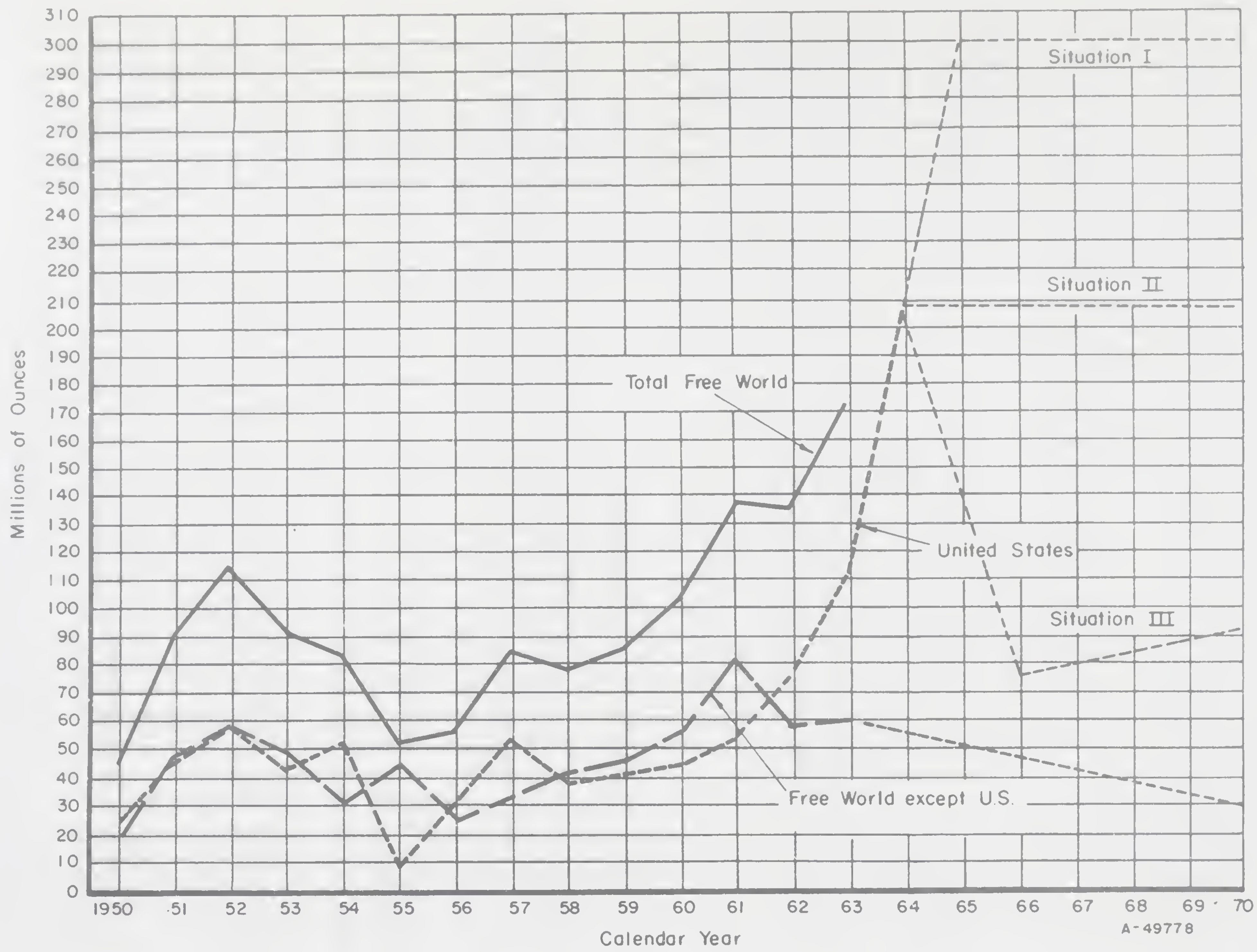

FIGURE B-6. QUANTITY OF SILVER USED IN COINAGE IN THE UNITED STATES AND IN THE FREE WORLD DURING THE CALENDAR YEARS 1950-1964 AND PROJECTED TO 1970

Table B-8 - Projected Changes in United States Monetary Stock of Treasury Silver for Alternative Compositions of Subsidiary Coins (millions of ounces).

		1963	1964[a]	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
	Projected Free World Deficit of Silver Excluding U.S. Coinage[b]													
	Production													
A	Total Free World[c]	210	220	229	239	248	258	265	270	275	279	282	285	286
	Consumption													
B	Industry & Arts[d]	247	252	257	262	267	273	278	282	288	294	300	306	312
C	Coinage-other Free World[e]	61	57	51	47	43	39	35	30	30	30	30	30	30
D	Total (B+C)	308	309	308	309	310	312	313	312	318	324	330	336	342
	Deficit													
E	Total free World (A-D)	(98)	(89)	(79)	(70)	(62)	(34)	(48)	(42)	(43)	(45)	(48)	(51)	(56)
F	Speculative & distribution of silver dollars		61	0	0	0	0	0	0	0	0	0	0	0
G	Redemption of Silver Certificates (F+G)	98	150[f]	79	70	62	34	48	42	43	45	48	51	56
	Projected Changes in U.S. Monetary Stock of Silver													
	I. Coinage Production at full Mint Capacity													
	Consumption of Silver for alternative silver content of coins													
H	90 Silver	111	208[g]	290	300	300	300	300	300	300	300	300	300	300
I	50 Silver	111	208	290	167	167	167	167	167	167	167	167	167	167
J	30 Silver	111	208	290	100	100	100	100	100	100	100	100	100	100
K	15 Silver	111	208	290	50	50	50	50	50	50	50	50	50	50
	Silver withdrawn from U.S. Treasury to finance total world deficit													
L	90 Silver (G+H)	209	358	369	370	362	354	348	342	343	335	348	351	356
M	50 Silver (G+I)	209	358	369	237	229	221	215	209	210	212	215	218	223
N	30 Silver (G+J)	209	358	369	170	162	154	135	142	143	145	148	151	156
O	15 Silver (G+K)	209	358	369	120	112	84	98	92	93	95	98	101	106
	Monetary Stock of Silver at end of calendar year													
	90 Silver	1584	1226	857	487	125	(229)	(577)	(919)	(1242)	(1597)	(1949)	(2296)	(2652)
	50 Silver	1584	1226	857	620	391	170	(45)	(255)	(465)	(677)	(892)	(1110)	(2333)
	30 Silver	1584	1226	857	687	525	371	236	94	(49)	(194)	(342)	(493)	(699)
	15 Silver	1584	1226	857	737	625	541	443	351	258	163	65	(36)	(142)
	No Silver as of 1/1/66	1584	1226	857	787	725	671	623	581	538	493	445	394	338

(a) These data for 1964 are based on projections made early in December, 1964, and therefore differ slightly from other data used in the text. The discrepancies have a negligible effect, however.

(b) Parentheses indicate deficits.

(c) Assumes maximum production of silver to 1968 and slowing in production, 1969-1975.

(d) Assumes increase in consumption of 2 per cent per annum.

(e) Assumes reduction in other Free World coinage to level of 30 million ounces by 1970.

(f) In addition, about 20 million ounces of silver were sold as silver dollars.

(g) Actual silver used in coinage for 1964 was 201.3 million ounces.


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Table B-8 (Continued)

II. Coinage Demand Steady at 1964 Level of Production

			1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
	United States coinage of silver - 1964 level of production														
A	90 Silver		111	208	208	208	208	208	208	208	208	200	208	208	208
B	50 Silver		111	208	208	113	115	115	115	115	115	115	115	115	115
C	30 Silver		111	208	208	69	69	69	69	69	69	69	69	69	69
D	15 Silver		111	208	208	35	35	35	35	35	35	35	35	35	35
	Redemption of Silver Certificates -														
E	Free World deficit		78	150	79	70	62	54	48	42	43	45	48	57	56
	Total Silver Withdrawn from U.S. Treasury														
F	90 Silver	(E+A)	189	358	287	278	270	262	256	250	251	245	256	259	264
G	50 Silver	(E+B)	189	358	287	185	177	169	163	157	158	160	163	166	171
H	30 Silver	(E+C)	189	358	287	139	131	123	117	111	112	114	117	120	125
I	15 Silver	(E+D)	189	358	287	105	97	89	83	77	78	80	83	86	91
	Monetary Stock of Silver Remaining in U.S. Treasury														
J	90 Silver	(J-F)	1584	1226	939	661	391	129	(127)	(377)	(628)	(875)	(1129)	(1388)	(1652)
K	50 Silver	(K-G)	1584	1226	939	754	577	408	245	88	(70)	(230)	(393)	(559)	(730)
L	30 Silver	(L-H)	1584	1226	939	800	669	546	429	318	206	92	(25)	(145)	(270)
M	15 Silver	(M-I)	1584	1226	939	834	737	648	565	488	410	330	247	161	70

III. Cyclic Downturn in Coinage Demand

			1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
	United States coinage - cyclic downturn beginning in 1965														
A	90 Silver		111	208	140	77	81	84	89	93	98	102	108	113	120
B	50 Silver		111	208	140	43	45	46	49	52	54	57	60	63	67
C	30 Silver		111	208	140	26	27	28	30	31	33	33	35	37	39
D	15 Silver		111	208	140	13	13	14	15	15	16	17	18	19	20
	Redemption of silver certificates														
E	Free World deficit		78	150	79	70	62	54	48	42	43	45	48	51	56
	Total silver withdrawn from U.S. Treasury														
F	90 Silver	(F+E)	189	358	219	147	143	138	137	135	141	147	156	164	176
G	50 Silver	(G+E)	189	358	219	113	107	100	97	94	97	102	108	114	123
H	30 Silver	(H+E)	189	358	219	96	89	82	78	73	76	78	83	88	95
I	15 Silver	(I+E)	189	358	219	83	75	68	63	67	59	62	66	70	76
	Monetary stock of silver remaining in U.S. Treasury														
J	90 Silver	(J-F)	1584	1226	1007	860	717	579	442	307	166	19	(137)	(301)	(477)
K	50 Silver	(K-G)	1584	1226	1007	894	787	687	590	496	399	297	189	75	(48)
L	30 Silver	(L-H)	1584	1226	1007	911	825	740	662	589	513	435	352	264	169
M	15 Silver	(M-I)	1584	1226	1007	924	844	776	713	646	587	525	459	389	313

The projected life of the U. S. monetary stock of silver held in the Treasury according to the previous assumptions is summarized in Table B-9.

TABLE B-9. SUMMARY SHOWING YEAR IN WHICH U. S. MONETARY STOCK OF SILVER WOULD BE EXHAUSTED, DEPENDING ON THE SILVER CONTENT OF THE COINAGE AND THE DEMAND FOR COINS

Level of Coinage Demand	Alternative Silver Content of U. S. Coins, per cent				
	90	50	30	15	0
I. High Level - Coinage production at full Mint capacity of about 300 million ounces per year	1968	1969	1971	1974[a]	1979[a]
II. Medium Level - Continuation of 1964 coinage rate of about 200 million ounces per year	1969	1971	1973	1976	1980
III. Low Level - Cyclic down-turn in coinage demand beginning early in 1965	1973	1975	1977	1979	1983

(a) It should be noted that industrial demand for 1964 was at a very high level. If it should increase at the rate of 2 per cent per year from this level, the Treasury stocks could be exhausted in 1971 for the 15 per cent silver content alternative, and in 1974 if no silver were used in coinage. Details of this calculation are shown in Table B-10.

TABLE B-10. PROJECTED CHANGES IN UNITED STATES MONETARY STOCK OF TREASURY SILVER UNDER CONDITIONS OF HIGH COINAGE DEMAND AND HIGH INDUSTRIAL DEMAND

(Millions of Ounces of Silver)

		1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
	Projected Free World Deficit of Silver Excluding U.S. Coinage												
	Production												
A	Total Free World	215	223	232	242	253	260	265	270	274	277	280	281
	Consumption												
B	Industry and the Arts	286	292	298	303	310	316	322	329	335	342	349	356
C	Coinage - other Free World	62	51	47	43	39	35	30	30	30	30	30	30
D	Total (B+C)	348	343	345	346	349	351	352	359	365	372	379	386
	Deficit												
E	Total Free World (A-D)	(133)	(120)	(113)	(104)	(96)	(91)	(87)	(89)	(91)	(95)	(99)	(105)
F	Redemption of Silver Certificates (-E)	141	120	113	104	96	91	87	89	91	95	99	105
	Projected Changes in U.S. Monetary Stock of Silver Assuming Coinage Production at Full Mint Capacity												
	Consumption of Silver for Alternative Silver Contents of Coins												
G	15 silver	203	300	50	50	50	50	50	50	50	50	50	50
H	0 silver	203	300	0	0	0	0	0	0	0	0	0	0
	Silver Withdrawn from U.S. Treasury to Finance Total Free World Deficit and to Produce U.S. Coinage												
I	15 silver (F+G)	343	420	163	154	146	141	137	139	141	145	149	155
J	0 silver (F+H)	343	420	113	104	96	91	87	89	91	95	99	105
	Monetary Stock of Silver at the End of Calendar Year												
	15 silver	1218	798	635	481	335	194	57	(82)				
	0 silver	1218	798	685	581	485	394	307	218	127	32	(67)	

APPENDIX C

COIN-OPERATED DEVICES

CONTENTS

APPENDIX C

COIN-OPERATED DEVICES

Kinds of Devices

Coin-operated devices dispensing a variety of goods and services have become commonplace in the United States. Two major categories of coin-operated devices are prevalent, namely, merchandise-vending machines and machines performing a service of some sort.

Merchandise-Vending Machines

The merchandise-vending machines, familiar to all, dispense such items as soft drinks, food, pocket combs, ice cubes, cigarettes, and small change for operating other such machines. This is a large industry. According to statistics presented by the National Automatic Merchandising Association, the sales from merchandise-vending machines alone will amount to about $3.8 billion in the 1964 calendar year, compared with $2 billion in 1957.

Coin Selection. Almost all of the 4 million merchandise-vending machines, except penny gum machines and the like, contain a device that detects various types of slugs and prevents all but a few of them from activating the dispensing mechanism. These devices are manufactured by three major companies, namely (in alphabetical order):

Coin Acceptors, Inc.
National Rejectors, Inc.
Reed Electromech, Inc.

All the devices operate on the same principles, which are discussed below. It is important to point out that these devices subject the coin to a series of tests designed to give an optimum degree of protection against slugs while accepting all or most of the genuine U. S. coins inserted in the machine.

Service-Vending Machines

Services dispensed by automatic machines include a number of well-established ones such as pay telephones and a number of newer ones such as automatic car-wash installations. Automatic washing machines and dryers, dry cleaning, juke boxes, and amusement devices (pin-ball machines) are additional examples of machines that perform services. Also included in this category are the self-serve collection baskets found on automobile toll roads and bridges.

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Coin Selection. Many of the machines that perform services do not contain the same highly sophisticated coin-selection devices as are used in the machines which dispense merchanidse. Most of these machines (an estimated 800,000), however, have simple devices which will prevent magnetic materials and oversized slugs from entering the coin box.

The trend is toward increasingly more selective coin-discriminating devices in service-dispensing machines. The pay telephones operated by Bell Telephone Company*, for example, have up to the present time accepted all disk-shaped pieces of metal that were not too large nor too small. Soon, however, Bell will install selectors capable of rejecting over 90 per cent of the slugs now accepted. An estimated 1,000,000 pay telephones will be altered.

Effect of Coinage Alloy on Coin-Operated Devices

From this brief description of the wide-spread use of coin-operated devices in the United States, it is evident that consideration must be given to the effect that any change in the coinage alloy will have on the industries involved.

Although the entire business of these industries is conducted with coins, a change to a coinage that cannot be accepted along with present coins will not prevent these industries from conducting their business. The principal consequence of such a change would be that the machines would not be as selective as they are now. This would mean a loss of revenue to the operators of "service" machines, and losses in goods by the merchandise vendors.

The magnitude of these potential losses cannot be estimated with any degree of accuracy at present.

Basis of Operation of Coin-Selecting Mechanisms

To a vending-machine operator, a slug is anything that can be used instead of a genuine U. S. coin in the operation of his machine. Thus, slugs may be brass washers, steel disks, play money, foreign coins, altered U. S. coins (such as a cut-down one-cent coin), or counterfeit U. S. coins.

Size. Several kinds of mechanisms are used to detect and reject slugs. The simplest of these is a sizing slot on the outside of the machines, preventing the insertion of slugs that are either thicker or larger in diameter than genuine coins. Cutouts in the coin rail inside the machine can be designed in such a way that undersized coins will fall through before reaching the actuating mechanism. Undersized coins are also checked in the weighing cradle (see below).

Magnetic Attraction. Another test which the coin must pass is that it not be attracted to a magnet. Any material that is attracted to a magnet is not a genuine U. S. coin since neither copper-zinc alloys (pennies), cupronickel (five-cent coin), nor silver-copper alloys (subsidiary coins) are magnetic.

*Total business volume in coins alone is $460,000,000 annually.

<u>Weight</u>. A coin that has been successfully inserted in the machine drops into a "cradle". The cradle performs a second test for correct diameter by catching the coin in a pair of curved arms if the diameter is correct; undersized coins drop through.

When the coin has lodged properly in the cradle, it comes to rest momentarily as the cradle, pivoted in an off-center position, is tipped by the weight of the coin. It is here that the coin is weighed. A small counterweight, carefully designed to permit rotation of the cradle by the relatively heavy silver-copper coins, will prevent rotation by coins made from light metals, such as aluminum. The coin is then cleared from the machine by various mechanical fingers.

<u>Washer Catchers</u>. At the instant the coin falls into the weighing and sizing cradle, a small wire probe pokes at the center of the coin. If the coin is a washer, the wire probe will enter the hole and prevent any further progress of the coin through the device.

<u>Eddy-Current Response</u>. Eddy-current action in a coin is a most critical test for genuine U. S. coinage.

A well-known principle of physics is that when an electrical conductor is moved through a magnetic field a current is generated in the conductor. In a disk-shaped conductor the current that is generated flows in small circular paths, which have come to be known as "eddy currents". The effect of these eddy currents is to create a second magnetic field which impedes the motion of the conductor through the primary magnetic field. The net result is that the disk is slowed down as it passes through the magnetic field.

The degree of retardation in the magnetic field will depend on the product of the density and the electrical resistivity* of the coin. When the rate of retardation is measured, it is possible to separate the genuine U. S. silver alloys from cupronickels, brasses, bronzes, stainless steels, copper, zinc, and many other metals which might have passed the tests for size, weight, magnetic attraction, and absence of center holes.

<u>Kinds of Coin-Selecting Mechanisms</u>

Some, or all, of the above-described principles of operation of slug-rejecting mechanisms are put to work in various devices.

With very few exceptions, every coin-operated device will reject slugs that are attracted by a magnet. Often, those machines which perform services will depend on a sizing slot and a magnet as the only rejection devices.

Merchandise-vending machines almost always have a device that checks the coin for eddy-current response, in addition to the other characteristics: size, weight, magnetic attraction, and absence of a center hole.

The eddy-current type rejector, in its rudimentary form is shown in Figure C-1.

*Resistivity is the inverse of conductivity.

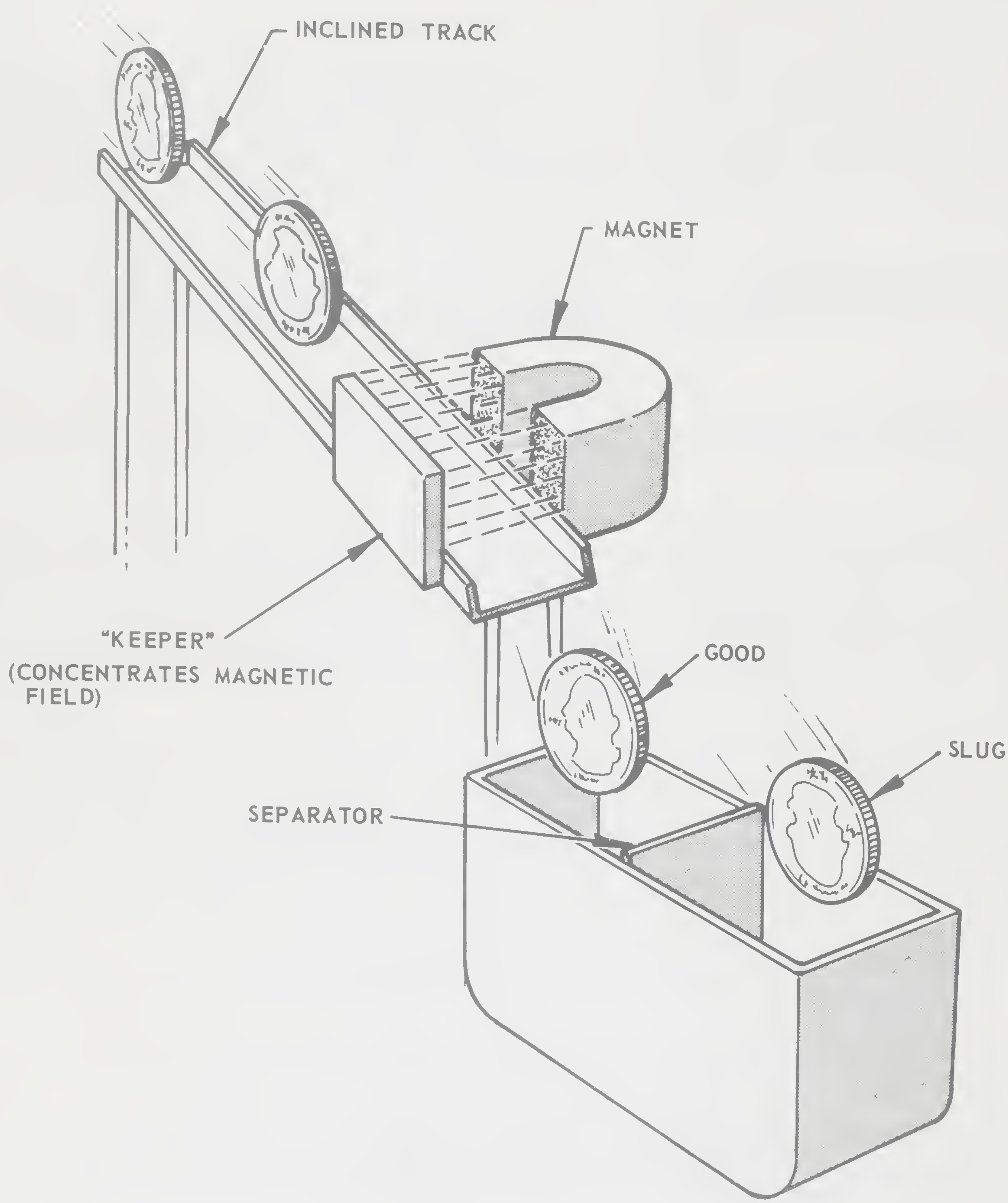

FIGURE C-1. EDDY-CURRENT TYPE OF SELECTOR (SCHEMATIC)

Physical Properties of the Present Silver Coinage Alloy

Since present coin-selecting devices aim to separate genuine U. S. coinage from slugs, it would be well at this point to review the physical properties of the 90 silver-10 copper alloy now used for subsidiary coinage and the relationship of these properties to coin-selector operation.

Thus, we find that the alloy has the following characteristics:

(1) High density

Density = 10.3 grams/cubic centimeter
Weight of dime = 2.5 grams
Weight of quarter = 6.25 grams
Weight of half-dollar = 12.50 grams

(2) Low electrical resistivity

Resistivity = approximately 2.1 microhm-cm

(3) Low resistivity x density

$$\text{Resistivity x density} = 2.1 \times 10.3 = 21.6 \, \frac{\text{microhm-g}}{\text{square centimeter}}$$

(4) Magnetic attraction

Nonmagnetic: will not be attracted to a magnet

Behavior of Candidate Materials in Present Coin-Selecting Devices

Lightweight Metals and Alloys

Alloys of aluminum, magnesium, and titanium, known as the light metals, would not be compatible with present coinage in today's coin-selecting devices. They are too light to permit the cradle to revolve when the coin rests in it. Probably adjustments could be made in the cradle counterweight to permit use of lightweight coins. A more serious difficulty, however, arises in the actuating mechanisms tripped by the coins after they have left the selector. Most mechanisms require a weight of 2.1 to 2.2 grams to permit actuation. Present coin-silver dimes weigh about 2.5 grams; aluminum dimes would weigh only 0.66 gram. Even aluminum 25-cent pieces would be too light to trip the switches.

A further difficulty with lightweight coinage might be encountered by motorists attempting to toss their coins into a toll highway basket-type counter on a windy day. Much havoc could result.

In general, therefore, light coins would cause considerable inconvenience in the coin-operated mechanisms. Alloying of the light metals with very heavy metals, such as tantalum or tungsten, would be required to make them acceptable.

Magnetic Metals and Alloys

Magnetic materials, that is, materials attracted to a magnet, would be rejected by all eddy-current-type selectors, all "slide-type" units found on many of the service-performing machines, and all toll highway self-serve collection baskets.

Some of the common classes of materials that would be attracted by a magnet are:

Nickel and many of its alloys
Cobalt and many of its alloys
Iron and many of its alloys.

Particularly important to note is that the 400-series stainless steels, which are principally iron-chromium alloys, are magnetic. Moreover, certain of the 300-series stainless steels, notably Types 301, 302, and 304, become slightly magnetic when coined, thereby making them unacceptable in many vending machines. On the other hand, very slight magnetic attraction might be used as a means of retarding the coin as it passes the magnets in the eddy-current section of the selector. This principle is the basis of a recent development by the International Nickel Company. Further discussion of this idea is presented below.

Metals and Alloys Having High Electrical Resistivity

Of the various candidate materials, almost all have higher electrical resistivity than coin silver. Because the product of electrical resistivity and density is so important to the coin-selector operation, it would be well to compare the candidate materials from this viewpoint. Table C-1 shows this comparison.

TABLE C-1. ELECTRICAL RESISTIVITY AND DENSITY OF SELECTED HIGH-RESISTIVITY MATERIALS

Name	Nominal Chemical Composition	Resistivity, microhm-cm	Density, g/cm^3	Resistivity x Density, microhm-g/cm^2
Aluminum Alloy 2024, age hardened	Al-4.5Cu-1.5Mg-0.6Mn	5.74	2.77	16
Aluminum Alloy X2020, age hardened	Al-4.5Cu-1Li-0.5Mn-0.2Cd	8.20	2.71	22
Gilding metal	Cu-5Zn	3.08	8.87	27
Commercial bronze	Cu-10Zn	3.92	8.81	35
Cartridge brass	Cu-30Zn	6.16	8.54	53
Columbium	Commercially pure Cb	14	8.60	120
Titanium	Commercially pure Ti	55	4.51	248
Nickel silver 65-18 (German silver)	Cu-18Ni-17Zn	29	8.73	253
Zirconium	Commercially pure Zr	40	6.48	259
75-25 Cupronickel	Cu-25Ni	32	8.95	286
Monel	Ni-32Cu	48	8.84	424
Type 301 stainless steel	Fe-17Cr-7Ni	72	8.05	580
Type 302 stainless steel	Fe-19Cr-10Ni	72	8.05	580
Nichrome V	Ni-20Cr	108	8.41	910

The metals and alloys listed in Table C-1 have been arranged in ascending order of the resistivity x density product. Present selectors in vending machines can be adjusted to accept coin silver (resistivity x density = 21.6) and reject pure copper (resistivity x density = 15.4) on the low side and copper-5 zinc on the high side (resistivity x density = 27). In practice, the adjustment limits may vary somewhat.

The important conclusion that can be drawn from Table C-1 is:

> Of the materials with electrical conductivity higher than that of coin silver, only two basic types are likely to pass the eddy-current test.

These two basic types are represented by aluminum alloy X2020 and the copper-5 zinc alloy. Any aluminum alloys with resistivities of about 8 to 8.5 microhm-cm would probably be acceptable, though there are few commercial alloys that would fit into this class. Various alloys could be compounded, however. The copper-5 zinc alloy is representative of the "modified coppers", which contain small amounts of such elements as phosphorus, cadmium, zinc, nickel, and manganese. In principle, then, the acceptable range of resistivity x density can be obtained by judicial alloying of either aluminum or copper to increase their resistivities, because both are lower in density than silver.

A further discussion of modified low-resistivity alloys follows.

Metals and Alloys Having Low Electrical Resistivity

Except for copper, aluminum, and gold, no metals approach the electrical resistivity of coin silver. Zinc, nickel, iron, columbium, and zirconium have many times higher resistivity than coin silver. Because of this, it is not possible to match the resistivity x density product of coin silver with any alloy except one based on metals lighter than silver. Even gold (if it were a candidate) would not be acceptable because of its very high density. Of the relatively light metals, only aluminum has a low enough resistivity to permit matching coin silver, with respect to eddy-current response.

As brought out in the previous section, the modified coppers may be suitable. Some of the commercial ones are shown below.

Name	Chemical Composition	Resistivity, microhm-cm
Deoxidized copper	Cu-0.02P	2.03
Zirconium copper	Cu-0.15Zr	1.99
Cadmium copper	Cu-0.9Cd	2.03

Examples of additions to copper, which would give alloys having resistivities of about 2.1 microhm-cm, are

Element	Weight Per Cent
Iron	0.04
Cobalt	0.06
Silicon	0.06
Arsenic	0.08

Element	Weight Per Cent
Chromium	0.09
Manganese	0.13

A small amount of zinc (2-3%) or nickel (0.5%) might also be used to produce the effect desired.

Silver-Copper Alloys. The class of alloys represented by the present coin silver (90 silver-10 copper) can be made in any combination of silver and copper from 90 silver-10 copper to about 95 copper-5 silver and still have the resistivity of coin silver. Therefore, the eddy-current response among a broad range of silver-copper compositions would be acceptable.

It should be noted that various silver-copper alloys have been used in other countries. However, when the simple 50 copper-50 silver alloys have been adopted, it has been found that discoloration was a problem. Solutions to this problem have involved additional alloying with zinc or nickel, which not only improve the corrosion resistance but also obscure some of the pink or yellow coloration due to the copper. Below are several examples of copper-silver alloys that at one time or another have been adopted by foreign governments:

Country	Alloy
United Kingdom	50 silver 40 copper 5 zinc 5 nickel
Sweden	40 silver 50 copper 5 zinc 5 nickel
Mexico	10 silver 70 copper 10 nickel 10 zinc

None of the above alloys have resistivities low enough to permit their use in the present-day coin selectors based on eddy-current response. Essentially, the increase in resistivity produced by the addition of nickel or zinc to the copper-silver combinations is the same as that produced when these additions are made to copper alone.

In sum, only the following classes of alloys would be satisfactory in their eddy-current response:

- High-resistivity aluminum alloys
- Modified coppers
- Silver-copper alloys.

Nonmetallic Materials

Plastics and ceramics both have very low density, which would preclude their use in present coin-operated devices. Moreover, they are electrical insulators and would show no response whatsoever in the eddy-current section of the coin selector. There is a possibility of making a composite consisting of low-resistivity metallic particles in a ceramic or plastic matrix, which might overcome some of these problems, but such developments would require a considerable amount of research to bring them to fruition.

Summary: Acceptable Materials

In the previous sections it was pointed out that:

- Lightweight metals – aluminum, magnesium, or titanium – would not be acceptable
- Magnetic metals or alloys would not be acceptable
- High-resistivity metal alloys would not be acceptable
- Ceramics and plastics would not be acceptable.

As a consequence of these restrictions, the only acceptable alloys are:

- Modified coppers
- Silver-copper alloys.

Further criteria of acceptance as coinage must be imposed on these two alternatives. Public acceptability is one criterion. Would a copper-colored coin be acceptable as a dime, quarter, or half-dollar? Because of the past association of copper-red alloys with coins of low denomination in many countries of the world, serious doubt must be voiced that such alloys would be acceptable as high-value U. S. coinage.

With the copper alloys, the incentive for illegal duplication is high. Moreover, an increase in slug making is possible because of the increased public knowledge that modified coppers will actuate coin-operated devices.

Silver-copper alloys present other difficulties, associated with the supply of silver. If the coin must be white-colored as well as corrosion resistant, it is extremely doubtful that any coin with less than 50 per cent silver can be a successful substitute for present coin silver. Substitution of a 50 silver-50 copper alloy for coin silver in all denominations of coins will not be possible on other than a temporary basis.* Consideration must be given, therefore, to the possibility of substituting 50 silver-50 copper for only one of the denominations. If this were feasible, the problem of substitute alloys for the other two denominations still would remain.

Possible alternative solutions are discussed below.

*See discussion of <u>Silver Supply and Demand</u>.

Alternative Solutions Relative to Coin-Operated Devices

Alternative 1. Modify Coin Selectors

Can the manufacturers of the various types of coin selectors modify them to accept other coinage? Undoubtedly, the answer would be yes if only new-coinage alloys were under consideration. Presently, for example, the eddy-current types of selectors can distinguish between genuine U. S. five-cent pieces and various types of slugs. In Japan, a pure nickel coin is distinguished on the basis of its unique magnetic characteristics. But the problem of designing a coin selector that would accept both the present U. S. silver coins and a new coinage is much more complex.

Two approaches are possible. Either a simple modification would be made by a service man or a complete new design worked out. Both of these approaches have pitfalls. Thus, simple adjustments, as presently comprehended, could indeed be made to accept both present coinage and cupronickel; but, if this were done, the device would lose some of its selectivity and would also accept brasses, zinc, nickel silvers, and possibly other less common alloys. Estimating the financial losses caused by this lack of sensitivity is beyond the scope of this study, but it is clear that some loss would occur.

The second approach, that of making a completely new coin selector or making a modification that required return of the device to the factory, would be a costly approach. Estimates for such modifications range from \$5 to \$60 each, for several million machines. However, the possible disturbance to the industry caused by the changeover would perhaps be more serious than the direct cost. Immediate changeover is not possible. Industry estimates of the time for complete changeover have ranged from 2 to 10 years.

Alternative 2. Composite Coins

An engineering materials problem that cannot be solved by using a single metal or alloy is often approached by combining two or more metals in such a way that each component of the combination performs a different function, while the composite meets the over-all requirements. An everyday example is copper-bottomed stainless steel pots and pans for cooking. Stainless steel, very resistant to corrosion by food and detergents, is not a good conductor of heat. Therefore, in stainless steel cookware, hot spots might develop and scorch the food. Copper, a good conductor, is applied to the bottom, which causes the heat to spread evenly and prevents scorching.

This principle can be applied to the coinage problem. We are confronted with the problem that the only alloys with low resistivity (besides the silver-copper alloys) are either too light or are red colored. The solution is then to make the light alloys heavy by combining them with a heavy metal, or to make the red alloys white by covering them with a white metal or alloy.

The possibilities of combining aluminum alloys with heavy elements are very limited because such heavy elements as tantalum or tungsten are not in abundant supply in North America. Another heavy element, spent uranium, is ruled out because of the emotional effects it might have on the public. Accordingly, composites involving aluminum are ruled out.

Various ways of making copper appear white are known. It can be plated with nickel, silver, or a number of alloys. Silver-plated copper alloys could be made to look like present coinage and act like present coinage in the vending machines.

Another way of making a white-looking copper alloy is to make a multilayer sheet from which blanks would be cut for coining. The multilayer would consist of a white metal covering on both sides of copper or a copper alloy. In principle, the copper, having low resistivity, would provide the eddy-current response, while the outer layer would provide the white appearance. Actually, the eddy-current response depends on the particular combination of metals and their relative proportions. A cupronickel (75 copper-25 nickel) clad on copper in the proportions shown in Figure C-2 has been found to behave satisfactorily in the eddy-current type of coin selectors.

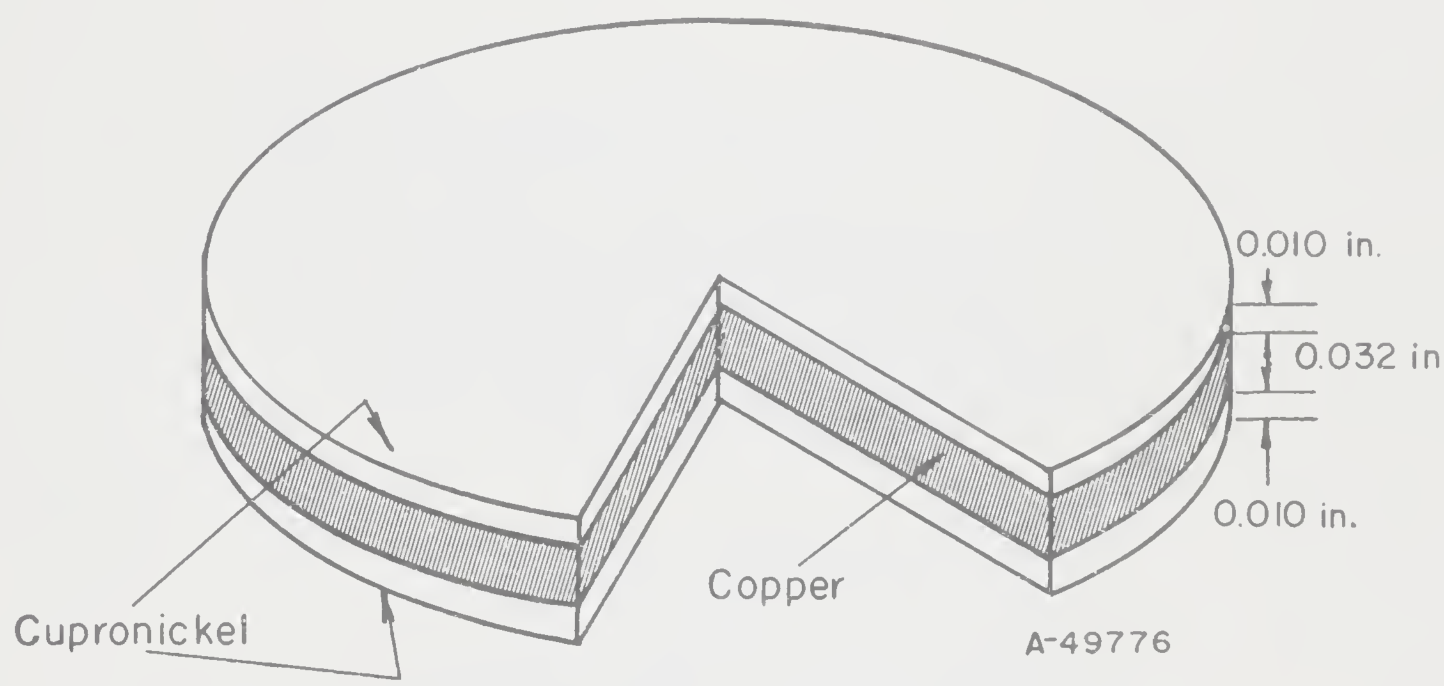

FIGURE C-2. MULTILAYER BLANK, 25-CENT SIZE

A variety of multilayer combinations are possible. For example, instead of cupronickel on copper, the following combinations might be possible.

Outer Layers	Core
90 Silver-10 copper	98 Copper-2 zinc
75 Copper-25 nickel	Various silver-copper alloys
70 Copper-30 silver	75 Copper-25 nickel

The first composite would behave the same as the present coinage, regardless of the proportions of clad and core. The last two would conserve silver but would have a white exposed outer edge rather than red, as shown in Figure C-2, which would be the case if the core were copper.

The disadvantages associated with this approach are: (1) a complete investigation of the manufacturing variables has not been made and (2) the Mint is not now equipped to manufacture such a material, so industrial sources must be acquired.

A third approach, based on the philosophy of composites, is a powder-metallurgical one. It might be possible to make a mixture of powders of silver or copper in a white-metal matrix such as cupronickel. If special procedures were followed, or a careful choice of matrix materials made, the result would be a composite consisting of a dispersion of low-resistivity metal in a white matrix. Figure C-3 is a schematic diagram of a powder-metallurgical composite.

The feasibility of this approach has recently been demonstrated by the Kawecki Chemical Company, using a columbium matrix. Several months of development work would be needed to establish manufacturing parameters. Mint production of coin blanks by compacting and sintering would be a vast departure from present processes, but these processes could be incorporated in the new Mint. In the interim period, the Mint would have to purchase blanks from industrial suppliers, though the lead time required for the production rates needed will be on the order of 6 to 18 months. A complete cost or technical evaluation of this approach has not been made at this time, but indications are that the cost of the blended powder would be about $15 per pound, and blanks perhaps $20 per pound.

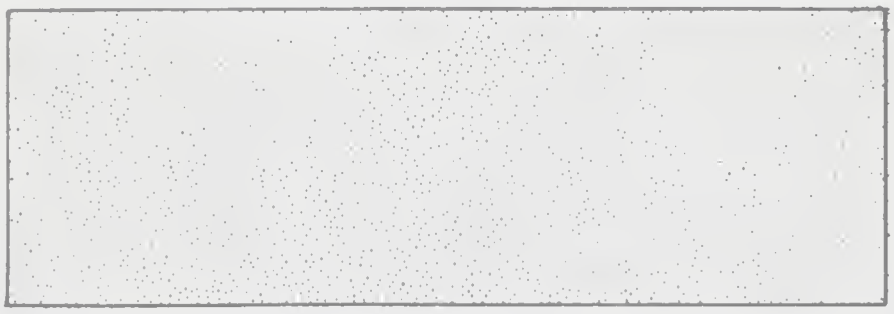

FIGURE C-3. CROSS SECTION OF POWDER-METALLURGICAL COMPOSITE (SCHEMATIC)

Dark spots represent copper or silver particles. Matrix is a white metal or alloy.

Alternative 3. Slightly Magnetic Materials

A third alternative has been proposed by the International Nickel Company. The basis of this proposal is the following:

> When a slightly magnetic coin rolls past the magnet in the eddy-current section of a coin selector, the coin is attracted to the magnet. As the face of the coin rubs along the magnet, the resulting frictional drag slows up the coin just as if it had been retarded by the eddy-current mechanism.

Proper behavior of a coin using this principle requires a very carefully controlled degree of magnetism. This has been achieved by making a composite consisting of a nonmagnetic material (95 nickel-5 silicon) that has been clad to a Permalloy core (80 nickel-16 iron-4 molybdenum). The magnetism of Permalloy can be controlled very closely. Only 1.5 per cent of the thickness of the 25-cent coin contains the

Permalloy, which is sufficient to produce the effect desired. The International Nickel Company has proposed that a piece of special tape be applied to the magnet poles of the various models of coin selectors. By so doing, the frictional drag can be made equivalent to the eddy-current retardation.

Because this method depends on friction, the rims of the coins would have to be redesigned to give a uniform rubbing surface. Otherwise, wear would progressively alter the action of the coin in a coin selector.

This composite was developed as a temporary coinage material that would be acceptable in coin-operated devices along with present coins. After the operators of coin-operated devices have had a chance to adapt their devices to accept coins with either high or low resistivity, the magnetic core could be eliminated. The nickel-5 silicon alloy would then be acceptable to all coin-operated devices.

An advantage of this proposal is that the composite is an all-white combination with a good appearance. The core makes up only 1.5 per cent of the cross-sectional area, and could therefore, be abolished (at the appropriate time) without any change in appearance.

At the present state of development, this approach has not worked completely satisfactorily in all coin-operated devices. Because the principle of operation is based on frictional drag rather than eddy-current retardation, more problems can be expected from this composite than from the multilayers, whose operation is based on eddy-current drag. Problems with wear of the coin, magnetic field variation, and alteration of the present devices, which would be minimal with the multilayers such as cupronickel on copper, would be troublesome to the nickel-5 silicon-magnetic core composite. Moreover, the Mint would be required to purchase the composite, since it is not now equipped to make it.

Evaluation of Proposed Solutions

If the coin-operated machine industry is given consideration, and if it is agreed that red alloys would not be well received by the public, then two of the above proposals seem to merit the most consideration:

(1) 50 Silver-50 copper alloy

(2) Multilayer materials consisting of either cupronickel on copper, or various other combinations of silver-copper alloys, copper, modified coppers, and cupronickel.

In the case of the 50 silver-50 copper alloy, some difficulties can be expected in Mint processing. Basically, however, the manufacture of this alloy should be within the present capabilities if minor changes in equipment are made.

The multilayer materials described are preferable to the composite involving a magnetic core. It would seem that if a composite is to be made at all, it should be based on the eddy-current principle rather than others. On the other hand, if the visible red edge is intolerable in the first case and combinations of white alloys are not feasible

for various technical reasons, the slightly magnetic nickel-base alloy composite should be given further consideration.

The principle problems yet to be fully established relative to the other multilayer composites are:

(1) Sources of supply of multilayer materials

(2) Manufacturing tolerances by suppliers

(3) Quality control in the Mint

(4) Effects of wear.

Some effort has been devoted to these problems, but more work should be done before a change-over to multilayer materials is undertaken.

One solution which would use a limited amount of silver is to clad copper with the Swedish alloy (50 copper-40 silver-5 nickel-5 zinc). This silver alloy would be preferred to the 50 silver-50 copper alloy because of somewhat improved tarnish resistance.

Before deciding on copper as the core composition, another factor to consider is that the annealing temperature of this metal is much lower than that of the clad. These temperatures should be as close together as possible. The addition of 25 to 30 troy ounces of silver per ton of copper, or 0.1 per cent zirconium, will raise the hot working and annealing temperatures by several hundred degrees Fahrenheit. An addition of about 1 per cent zinc will raise the resistivity slightly, thereby improving the discrimination of the coin selector.

Accordingly, the following specification is offered tentatively, as the material for all denominations of subsidiary coin:

(1) Chemical Composition

Outside layers: 40 per cent silver
50 per cent copper
5 per cent nickel
5 per cent zinc

Core: silver-bearing copper (25-30 oz/ton), containing 1 per cent zinc

(2) Layer Thicknesses in the Strip Used for Blanking (40 per cent outerlayers, 60 per cent core)

Coin Denomination	Nominal Over-All Strip Thickness, inch	Nominal Thickness of Outside Layers, inch	Nominal Thickness of Core, inch
Half-dollar	0.067	0.0134	0.0402
Quarter	0.052	0.0104	0.0312
Dime	0.039	0.0078	0.0234

C-15 and C-16

The outside layers comprise 41.3 per cent by weight of the over-all composite; the over-all silver content is 16.5 per cent by weight.

This combination could be changed to cupronickel on copper at any time, without changing the thicknesses. If the 1 per cent zinc is not included in the core material, no change in behavior in coin selectors will occur.

APPENDIX D

MINT OPERATIONS

CONTENTS

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APPENDIX D

MINT OPERATIONS

Description of Mint Operations

Introduction

An important criterion which must be used in rating a possible alternative material for the current coinage alloys is the ability of the Mints to make coins from the material.

Congress has recently authorized a new Mint, to be located in the city of Philadelphia. The new facility will incorporate modern melting, rolling, annealing, and coining machinery capable of handling a number of the alternative materials that may be selected for new coinage. However, the new Mint is not expected to go into production for several years. As a result, the present Mint facilities must handle the production of coins from the new material until the new Mint is ready.

The Mint has for years been an integrated operation with essentially complete control of all aspects of coinage from the melting of the alloys to the coining operation, including final inspection, counting, and bagging of the finished coins. For most of its history, the Mint has used only three alloys in making coins for the United States. These alloys are processed through the Mint as shown in Figure D-1. Each of the important steps will be considered separately. All the steps described were observed at the Philadelphia branch of the Mint, but the Denver branch has essentially the same setup.

Melting and Casting

In the Mint melt shop, the required amounts of metal for the alloys used are weighed out and charged cold into 750- pound-capacity high-frequency induction furnace units. Each unit has an available power supply of 200 kw. Clay graphite furnace linings are generally preferred, particularly for the current silver alloy. During recent operation, the melting and casting facilities have been devoted exclusively to the 90 silver-10 copper alloy. There is not enough capacity to handle the melting of all three coinage alloys at this time. The result is that coiled alloy strip, required for one-cent and five-cent pieces, is currently being purchased from outside vendors.

Molten silver coinage metal is cast into rectangular slabs in water-cooled, copper-faced "book" molds, yielding an ingot 1-1/2 inches by 9-3/8 inches* x 5 feet long weighing about 315 pounds. This slab ingot requires no surface preparation, other than wire brushing, and goes directly to the rolling mills for a cold reduction pass.

*12-inch-wide slabs are made at the Denver Mint.

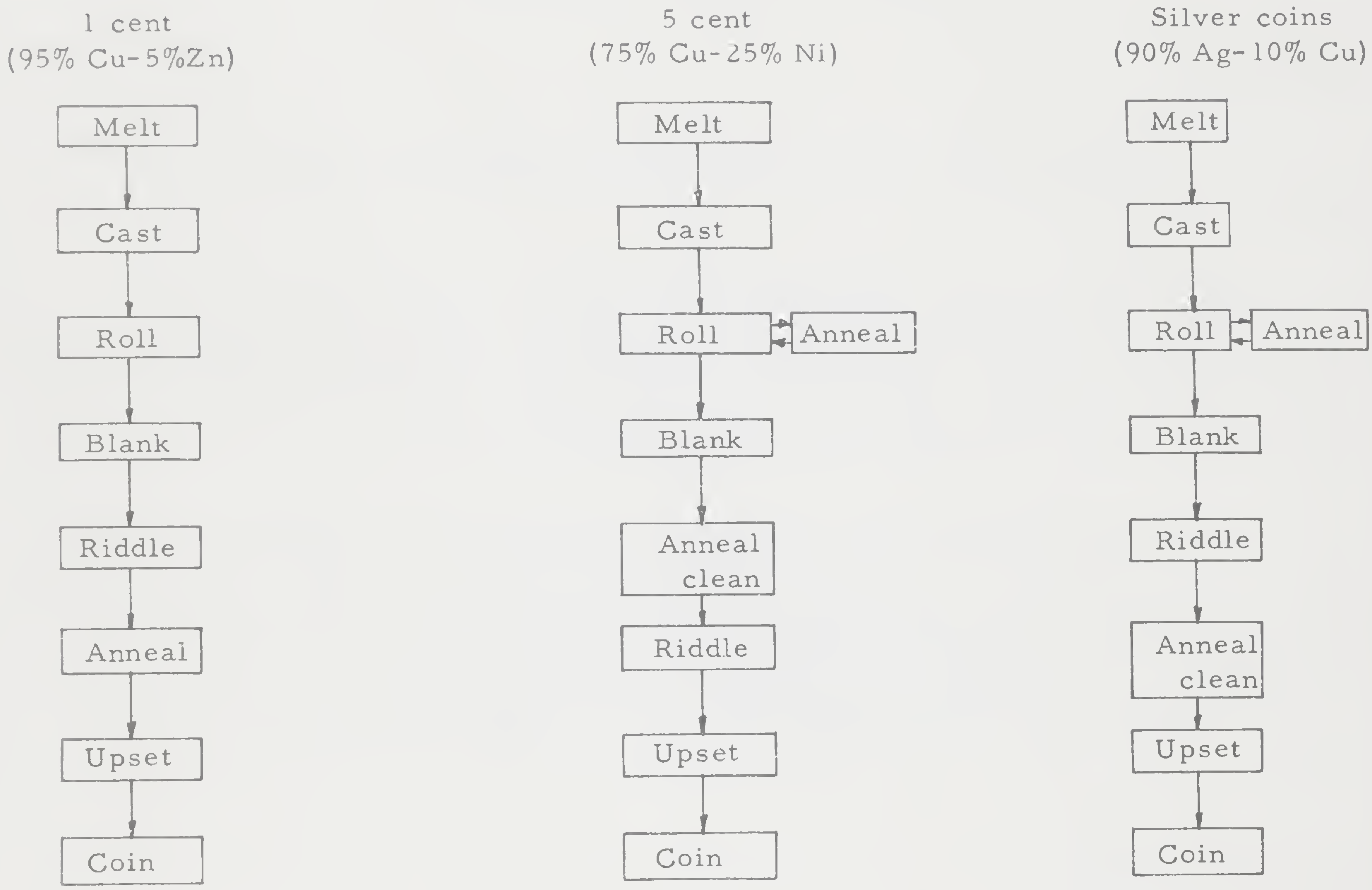

FIGURE D-1. BASIC MINT COIN PROCESSING

The introduction of alternative metals and alloys such as nickel, nickel-chromium, or stainless steels would require a change in melting practice and different furnace linings. It could also mean an alternation of the casting technique and equipment to safely and efficiently handle the higher-melting-point materials. A much more drastic change would be necessary were the Mint required to melt and cast the so-called refractory or reactive metals such as titanium, zirconium, or columbium. Consumable-electrode vacuum-arc type melting equipment is required. Contamination by gases such as oxygen and nitrogen must be kept at a minimum because such contamination, even in small amounts, sharply increases the hardness and decreases the workability of these metals.

Of the metals and alloys already suggested as possible alternatives for 90 silver-10 copper, the cupronickel, nickel silver, and various silver-copper alloy modifications are the only white alloys that could be handled in the present melting equipment. Most copper-base alloys could also be handled. The melting and casting of the present silver alloys at the Mint has reached a high degree of perfection and efficiency, and the product is consistently of the highest quality as is evidenced by the excellent coins that are made from the ingots.

Rolling

The Mint is presently capable of cold rolling such alloys as cupronickel, 90 silver-10 copper, and most copper-base alloys. No provisions have been made for heating ingots or slabs to hot roll them. A furnace for annealing between cold reduction passes is available. For example, the current high-silver alloy is rolled to size with two intermediate anneals with about a 50 per cent cold reduction of the cast slab before the first anneal. The cold rolling to final size prepares the strip for blanking, which could not be carried out in a satisfactory manner if the strip were annealed.

All the present coinage alloys are handled by cold rolling and annealing with no difficulty. However, alternative alloys, such as the stainless steels, the high-nickel alloys including nickel-5 silicon, titanium, and zirconium would require rolling techniques and equipment not now available at the Mint. Special annealing equipment would also be required and, in the case of metals such as titanium, columbium, and zirconium, protection from gaseous contamination would be required during annealing. Columbium, on the other hand, does not work harden rapidly during cold rolling and it could perhaps be reduced without intermediate annealing. However, it is probable that at least one annealing treatment would be required before coining, regardless of what metal or alloy were chosen.

In connection with rolling operations, a smooth, clean surface is required to produce high-quality coins. With the present alloys, a good surface is maintained without any special descaling or pickling steps. Some of the alternative metals and alloys might pose a problem in this respect unless the Mints bought the material from outside vendors rolled to the final finish and size desired. It is doubtful, that the Mint's rather old rolling equipment could properly handle most of the alloys which have been suggested as possible alternatives to the current silver alloy.

Blanking

After the coin metal is rolled to the proper thickness, it is sent through the coin blanking machines, which punch out the coin blanks or planchets. With the present alloys, this is done with the strip in the cold-rolled condition, as this results in the blank having a clean and sharp sheared edge. If annealed before blanking, the punch drags the metal and leaves an unsatisfactory burred edge. Although the blanking step presents no particular problems, some of the possible alternative metals may be more difficult to punch, with the result that die life would be shortened.

The blanking operation produces about 30 per cent scrap, the inevitable result of punching circular blanks from strip stock. With the present coinage alloys, the blanking scrap presents no problems. Scrap from each of the alloys is (or can be) readily reverted into the melting cycle. However, with certain alternative materials such as a composite made by cladding cupronickel to a 50 silver-50 copper core, the blanking scrap could not be simply remelted. In a case of this type, it would be necessary to process the scrap in such a way as to separate the silver, copper, and nickel. The separation of these metals, however, is not difficult. The monetary value of the scrap would be based on the value of the metals recovered minus refining and handling charges. On the other hand, scrap from a composite of cupronickel clad on copper could be reverted directly for production of the present 5-cent coin or for production of the cladding of the cupronickel-copper composite. If the Mint were purchasing such alternative metals as titanium, zirconium, or columbium in strip form, the blanking scrap would have to be carefully segregated and returned to the outside supplier for remelting and reprocessing. The reprocessing costs would be relatively high for these metals, perhaps as much as 75 per cent of the original cost of the rolled product.

Upsetting

In the upsetting operation, the coin blanks or planchets are passed between rolls to raise or upset the rim of the blank. The rim thickness is greater than that of any other part of the coin, providing some protection against wear of the central portions of the coin. Also, as long as the rim is thus raised the coins will "stack" properly.

Coining

The coining process is a critically important part of the total Mint operation; it provides a very real test of any material suggested for use in coinage. During the coining operation, the coin blank is pressed simultaneously between obverse and reverse dies to form the complete design, including the milled edge ("reeding") when the latter is required. For 1-cent, 5-cent, and 10-cent coins, the press capacity is large enough to handle a pair of dies, so that one stroke of the press produces two coins. Coinage presses operate at about 140 strokes a minute, so that each press can produce about 280 pennies, nickels, or dimes per minute. The quarter dollar and half-dollar, being larger in area, require more pressure for coining and only one coin is produced for each stroke of the press.

Generally speaking, the coining presses are quite old and limited in capacity. According to Mint personnel, the design load limit of these presses is 150 tons. Currently, the presses are operating at, or slightly in excess of, their rated load.

The introduction of new coinage alloys of higher strength and hardness than the present alloys could impose a severe strain on the presses, even for the small-size coins. This might mean that only single-coin dies could be used instead of dual ones, with a resultant lowering of production rate. Larger coins such as the half-dollar may be very difficult or even impossible to coin from high-strength material on the present equipment. For example, difficulty was experienced when the Mint made coins for Costa Rica from a 17 per cent chromium stainless steel, in spite of the fact that the design or embossing was relatively shallow as compared with that on United States coins.

The coining die, as distinct from the press, can withstand only a limited pressure. Excessive wear and possibly cracking would be the result of using harder or more abrasive materials that require high coining pressures. This would cause more down time, not only as the result of higher stresses imposed on the old presses, but also because of the need to replace dies more frequently.

Results of Coin Striking Trials

A number of the possible candidate materials were selected and taken to the Philadelphia Mint in the form of rolled strip to determine how well they could be blanked, upset, and coined. Table D-1 lists the materials and observations on the results. The rolled strip material, in the proper thickness for the particular coins desired, was first blanked and upset as in normal Mint practice. For the actual coining step, special dies were prepared by the Mint designers and engravers, which would duplicate as nearly as possible both the obverse and reverse design features of a typical dime, quarter, and half-dollar. Coining was done on a hydraulic press instead of on a mechanically actuated production coin press. The strain rate in the hydraulic press is much lower than that in the "knuckle" presses normally used for coining, which might influence the plastic behavior of the metal as it is pressed between the coining dies.

The materials chosen for the Mint tests were representative of the classes of materials listed in Table 3 in the main body of this report. Some of the metals, such as pure nickel, aluminum, copper and copper alloys, were known to be readily coinable. Cupronickel, for example, was familiar to the Mint as the alloy used in the five-cent coin, but it has not been used in the larger sizes such as the quarter, dollar, and half-dollar sizes. The various silver-copper alloys and their modifications represented dilute silver alloys that are white and compatible with present vending-machine requirements. Columbium and zirconium represented exotic metals which under certain qualified conditions, were considered as possible candidate materials. The nickel-base alloys were represented by Monel and a special nickel-5 per cent silicon alloy containing a Permalloy core. Austenitic stainless steels were represented by Types 301 and 302.

The data in Table D-1 show that there was no difficulty in blanking any of the materials. However, coin blanks of some of the materials did not upset properly during the edge-rolling operation. For example, two of the composite materials, the silver-clad copper and the cupronickel-clad copper tended to buckle during the edge-rolling operation. The problem was more pronounced with the quarter-dollar-size blanks than with the 10 cent size blanks. Photomicrographs, Figures D-2 and D-3, show that the bond between the outside layers and the copper successfully withstood the blanking and upsetting operations. The cause of buckling may have been

TABLE D-1. COINAGE TESTS OF CANDIDATE METALS AND ALLOYS

Material	Coin Sizes	Blanking	Upsetting	Coining Operation(a)	Remarks
50 Silver-50 copper(b)	10¢, 25¢, 50¢	Satisfactory	Satisfactory	Satisfactory, all sizes	
75 Copper-25 nickel (cupronickel)	10¢, 25¢, 50¢	Satisfactory	Satisfactory	Lettering next to rolled edges not filled out in some places; otherwise very good	10 cent size very good
Cupronickel-clad copper	10¢, 25¢	Satisfactory	Some difficulty(c)	Some blanks bent; coins generally good; very good 10-cent size	Blanks tended to buckle during upsetting operation
90 Silver-10 copper clad on copper	10¢, 25¢	Satisfactory	Some difficulty	Imperfect rim area, probably improper edge rolling; otherwise generally good	Blanks tended to buckle during upsetting operation on 25-cent size; 10-cent size coined very well
Columbium	10¢, 25¢	Satisfactory	Satisfactory (unannealed)	Appearance of coin good; design & lettering sharp; 10¢ coined very well	Coin dark gray, but not unpleasant appearance, blanks did not dish when upset
Zirconium	25¢	Satisfactory	Difficulties	Design not quite filled out next to rim	Blanks dished during edge-rolling operation, coins also dished with obverse design above rim
Monel (commercial)	10¢, 25¢	Satisfactory	Poor 25¢ size Fair 10¢ size	Design not filled out next to rim; coin convex on obverse side above rim	25-cent blanks dished badly during edge rolling; 10-cent size fair, but some dishing
Austenitic stainless steel, Type 301	10¢, 25¢, 50¢	Satisfactory	Poor	Unsatisfactory; design did not come up, particularly adjacent to the rim	Upset blanks were dished; coins were concave on reverse side, with obverse convex above rim
Austenitic stainless steel, Type 302	25¢	Satisfactory	Poor	Same as Type 301 stainless steel	Blanks dished severely during edge rolling; coin concave on reverse side, with obverse convex above rim
Nickel-5 silicon-Permalloy (Inco)	10¢, 25¢, 50¢	Satisfactory	Some difficulty	Good when annealed between edge rolling and coining	Edge rolling produced severe and extensive cold work at rim; design did not come up in areas adjacent to rim unless annealed after upsetting

(a) Coining pressure used for 10-cent, 25-cent, and 50-cent coins was 65, 105, and 135 tons, respectively. Pressure was established with standard 90 silver-10 copper alloy blanks.

(b) In addition to the 50 silver-50 copper alloy, the following silver-copper alloys, modified silver-copper alloys, and nickel silver were struck.

	Composition, per cent			
Code	Silver	Copper	Nickel	Zinc
K	50	40	5	5
L	40	50	5	5
M	33.3	66.7	-	-
N	40	58	-	-
P	30	68	-	-
Q	20	78	-	-
R (Nickel Silver)	0	65	18	17

All of these alloys coined well.

(c) Edge rolling produced a roughened surface near the edge of the coin in some instances. The effects were noticeable after coining. This problem could probably be controlled by modification of rolling-and-annealing procedures.

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FIGURE D-2. EDGE OF BLANKED CUPRONICKEL-ON-COPPER COMPOSITE MAGNIFIED 50 TIMES

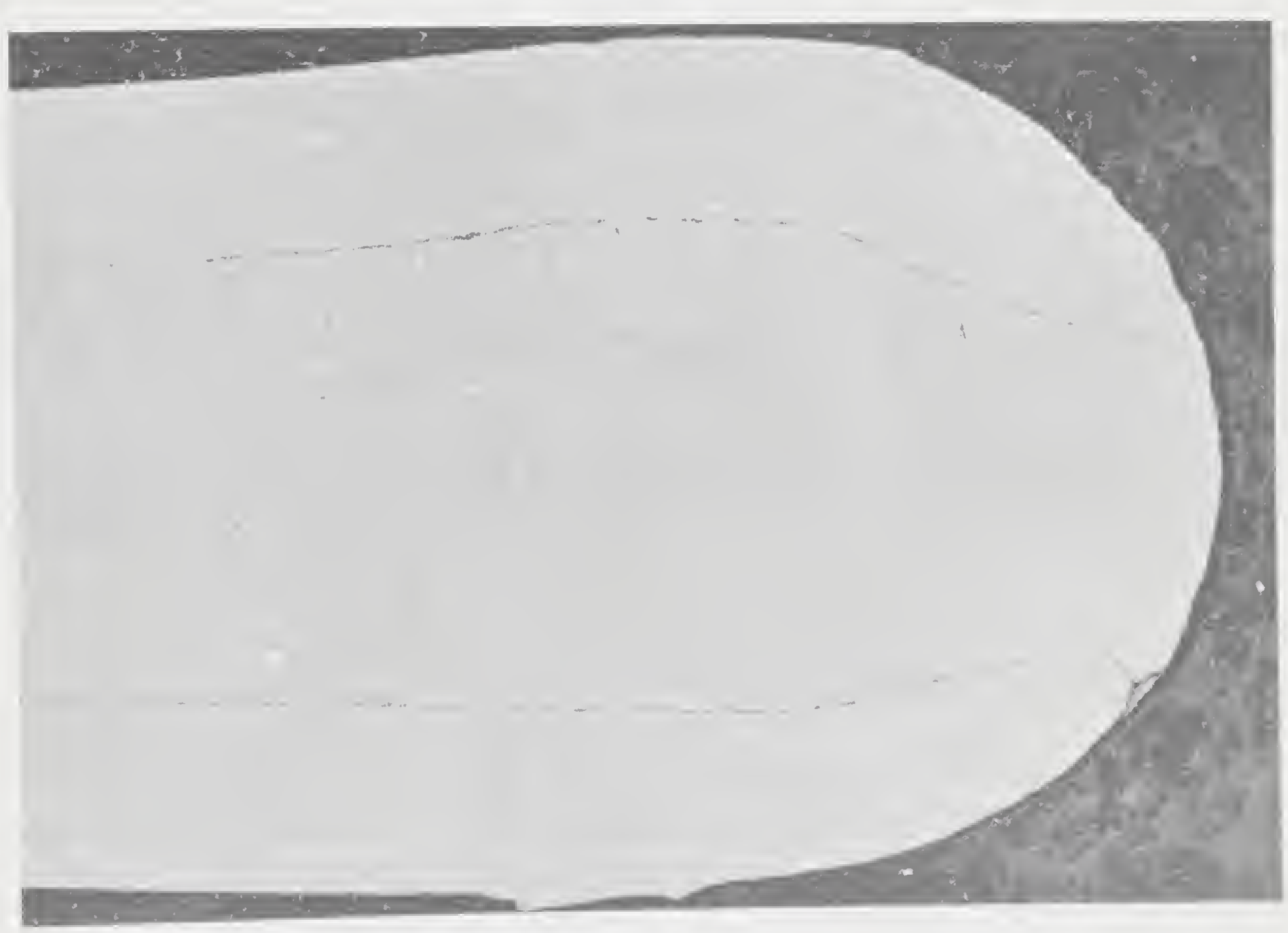

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FIGURE D-3. EDGE OF UPSET BLANK OF CUPRONICKEL-ON-COPPER COMPOSITE MAGNIFIED 50 TIMES

over-annealing of the material. However, it is felt that this condition could be corrected easily by proper selection of the annealing conditions. It was also noted that the edge-rolling operation cold worked the edge of the blank to a greater depth than anticipated. During the subsequent coining operation, this condition appeared to cause trouble in getting a full development of the lettering in the design that is adjacent to the rim of the blank. This condition was particularly severe in the austenitic stainless steels and the nickel-5 silicon alloy. To alleviate this would require an extra annealing treatment after upsetting or edge rolling to soften the rim of the coin. To prevent buckling of the blanks during upsetting, it would probably be better to anneal following the upsetting, rather than before. This would also soften the material in the outer portion of the blank. This procedure was actually tried with another set of the nickel-5 silicon blanks and the results were satisfactory.

Figures D-4, D-5, and D-6 show the results of coin-striking experiments. The coining operation revealed difficulties in striking zirconium metal, stainless steel, and Monel. However, the magnitude of the coining pressure for all these experiments with the alternative materials was established by trials with the current silver-base alloy as a standard. As a result, some of the alternatives might have shown up more favorably if higher pressures had been employed during coining. However, as indicated earlier, the cold work introduced into the rim area of the coin during edge rolling results in a low capacity for plastic flow in this region during coining. This deficiency might be mitigated by annealing the upset blank before coining, as was done with the nickel-5 silicon alloy.

In general, it may be concluded that the stainless steels, whether they are the austenitic or the straight-chromium types, would be difficult to coin with the present equipment. On the other hand, a stainless steel has recently been developed by Republic Steel Corporation, which promises to have higher coinability than the other stainless steels. The alloy has not been tested in Mint coining dies, however. Nickel-chromium alloys and Monel also lack coinability. However, the lack of coinability of most of these alloys would be only one part of the Mint's problem. As mentioned earlier, these materials also require different melting procedures than used with present alloys, and they require hot-rolling equipment. Furthermore, annealing of the austenitic stainless steels requires fairly high temperatures (about 1900-2000 F), followed by a water quench. Such facilities are not now available. Nickel, nickel silvers, and the nickel-5 silicon alloy are not as difficult to handle as are the stainless steels but, with the possible exception of nickel-silver alloys, the Mints are not now equipped to handle their melting and rolling.

The coinability of zirconium was found to be questionable, and further experimentation is needed. Although titanium was not tried at the Mint, its properties indicate that it would be very difficult to coin. No experiments were made in coining pure nickel, but its coinability has been well established by the Canadian Mint, which now makes a five-cent coin from pure nickel. Thus, from the standpoint of coinability, the acceptable white metals are: nickel, cupronickel, columbium, the silver-copper alloys and their modifications, and composites consisting of cupronickel clad on copper and coin silver clad on copper.

19706

FIGURE D-4. EXPERIMENTAL STRIKES MADE AT THE PHILADELPHIA MINT ON 25-CENT-SIZE DIES

F: 75 Copper - 25 Nickel
103: Cupronickel - Copper Multilayer Composite
D-2: 50 Silver - 50 Copper
102: Coin Silver - Copper Multilayer Composite

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FIGURE D-5. EXPERIMENTAL STRIKES MADE AT THE PHILADELPHIA MINT ON 25-CENT-SIZE DIES

101: Columbium, Vendor I
110: Columbium, Vendor II
107: Zirconium
105: Monel

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FIGURE D-6. EXPERIMENTAL STRIKES MADE AT THE PHILADELPHIA MINT ON 25-CENT-SIZE DIES

108C: Nickel-5 Silicon with magnetic core (bright annealed after upsetting)
G: Type 301 Stainless Steel, Vendor I
106: Type 301 Stainless Steel, Vendor II
109: Type 302 Stainless Steel

Conclusions

The results of the blanking, upsetting, and coining experiments, considered in conjunction with the other Mint processes, lead to the general rating of alternative materials shown in Table D-2.

TABLE D-2. GENERAL RATING OF ALTERNATIVE COINAGE MATERIALS[a]

Material	Mint Operations					Remarks
	Melt	Roll	Blank	Upset	Coin	
75 Copper-25 nickel (cupronickel)	+	+	+	+	+	
All silver-copper alloys and their modifications	+	+	+	+	+	Slight modifications in rolling and coining
Cupronickel clad on copper	-	+	+	+	+	Adjustments in upsetting required
Coin silver clad on copper	-	+	+	+	+	Adjustments in upsetting required
Columbium	-	0	+	+	+	
Zirconium	-	0	+	+	0	
Nickel-silicon	-	0	+	+	+	Some change in annealing procedure required
Monel	-	0	+	+	-	
Austenitic stainless steel, Type 301	-	-	+	0	-	
Austenitic stainless steel, Type 302	-	5	+	0	-	
Nickel[b]	-	-	+	+	+	
Titanium[c]	-	-	+	+	-	

(a) The rating key is as follows:
+ = Satisfactory now
0 = Needs some modification or further experimentions
- = Not feasible now.

(b) Coinability rating based on Canadian Mint experience.

(c) Titanium not actually tested, but coinability rating based on its properties.

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